AN INTEGRATED DISPLAY AND CONTROL SYSTEM FOR MAN-MACHINE COMMUNICATION

CURTIS G. LAWSON

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Captain, United States Marine Corps

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the requirements for the degree of

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ABSTRACT

Computer oriented systems have created the need for a closer interaction between men and computers. This thesis is an evaluation of, and the resulting system design of one such system. The main portion of the design is that of the operator's display and control console for this system. Included as a portion of the design problem is a computer program for the mechanization of wiring data for constructing the digital equipment.

The operator's display and control console is presently being constructed by Data Display, Incorporated of Saint Paul, Minnesota.

The author wishes to express his appreciation to Professor Mitchell L. Cotton of the U. S. Naval Postgraduate School, and to Mr. G. N. Grashorn of Data Display, Incorporated for their many helpful suggestions.

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1. Man-Machine Communications in a Digital System

The present use of computers in most applications can be classified as one of two categories:

a. Off-line operations in which a preformulated problem and precoded groups of data are fed to the computer along with the programs for processing the information. The computation then proceeds according to the preplanned program, if all data and programs are correct. Upon completion of a successful program, the desired results are then dumped from the computer memory to an output media for printing and evaluation at some later time. The extension of this technique has led to the "closed shop" computing center with their various "auto-monitor" programs in which the individual who wants the problem solved never sees the computer. This technique was prompted by the expense of large digital computers. The major drawback to such a scheme is that in writing new programs or trying to formulate new techniques for solving problems, there is a good chance for errors which will not allow the program to run to completion and may not give any indication of the reasons for stoppage. The cost of off-line formulation and "de-bugging" may be considerable in some circumstances.

b. On-line operations in which the operator is working in real time with the computer on a real time physical problem. This type of operation traditionally employs programs which are necessarily complex to take every possible situation into consideration. The role of the man in this system has been to make simple "yes-no" or similar decisions and to provide a means of accomplishing tasks

which are not automated or programmed whether by reason of difficulty or just oversight. Examples of on-line operation are the military systems (i.e., SAGE, NTDS, etc.) and industrial process controls. The cost of such systems are large as the computer is usually in full time use by the system due to the special purpose nature of the equipments.

There has been a recent trend to explore the possibilities of utilizing the best points of both techniques in systems linking man and computer more closely /1, 2/. In order to accomplish this, the basic class of operation must tend toward on-line operation. By having a closer link with the computer, the operator can make decisions at various points in the process based on real time feedbacks; examine changes in results due to varying inputs or parameters in real time; program and check blocks of codings easily before integration into a more complex program; and call up and inspect large blocks of information randomly from a large memory.

In order to accomplish this interaction between man and computer while keeping the overall system flexible and relatively inexpensive, certain requirements must be met: (a) A method of time sharing of the central computer must be implemented whether by programming or hardware techniques. (b) Display and control equipments must be designed to allow the operator to effectively communicate complex ideas to the computer and to allow the computer (through proper programming) to make requests on or display data to the operator. The first requirement is dictated by the desire to perform on-line and off-line computations interlaced in

time, while the second is essential to any closely coordinated man-computer system. The specifications of time sharing systems have been developed in recent literature /28, 29/. It is the purpose of this thesis to develop design criteria and to carry out the design of a display and control console which can be applied to many different type problems.

In a computer oriented system the flow of information is as shown in Figure 1-1.

The man-computer interface consists of two unique parts. There must be a provision for the operator to communicate his desires to the computer, and the computer should have the provision to display results or ask for further instructions. Specific techniques for accomplishing these functions will be discussed in Chapter 2.

In order to intelligently use any or all of the possible information available in a complex system, the display must be able to select various portions of information readily and easily. This means that the display console itself should be a complex buffer and should be able to control the computer's memory and programs. The main control programs in the central computer should be tailored to the display which in turn should be tailored to the human requirements for ease of operation along with flexibility.

Display updating may be done on any of the following criteria:

a. Upon receipt of new data by the computer

b. Upon a real time interval

c. Upon request from the display console

Priority considerations in the case of radar or automatic inputs

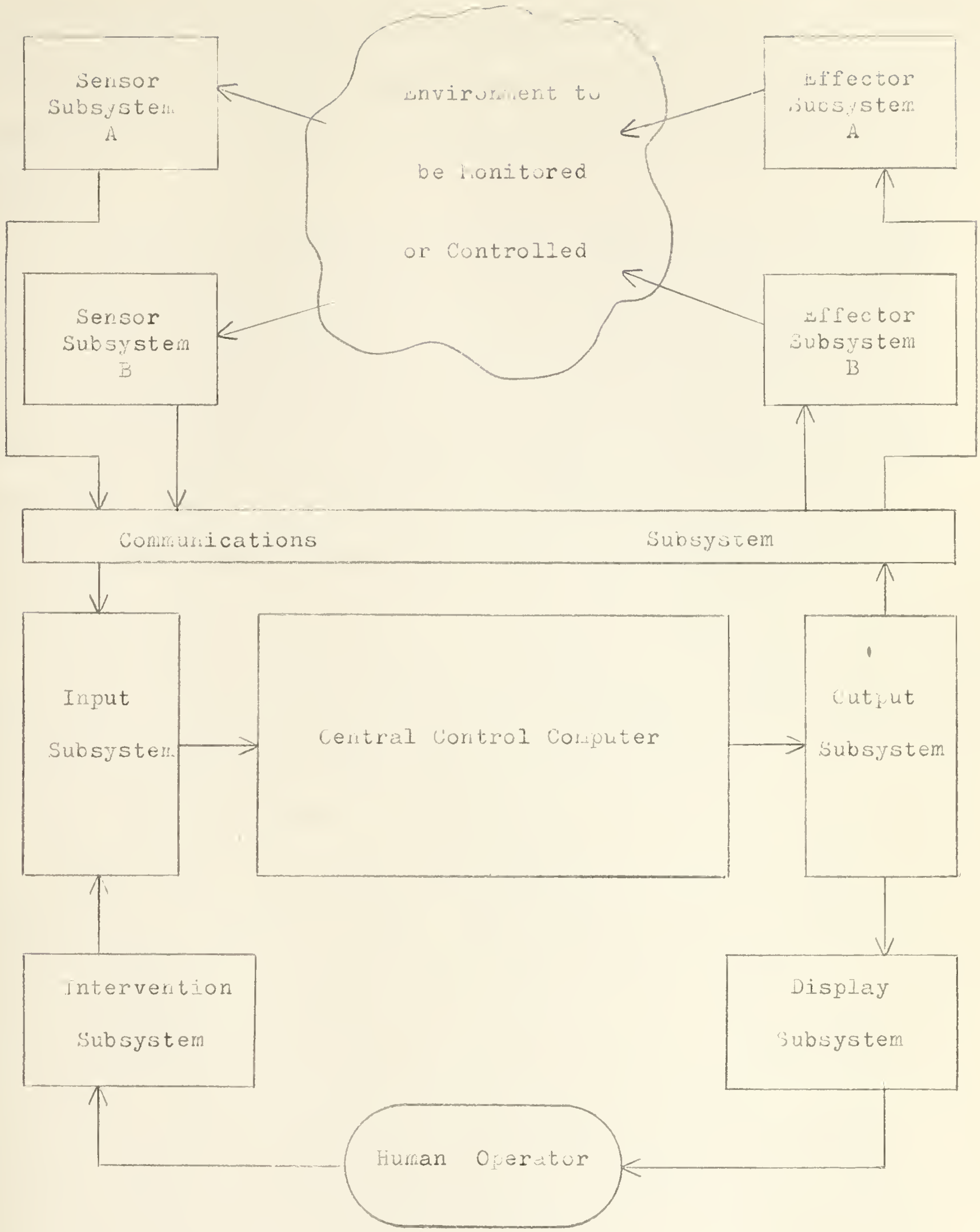


Figure 1-1
Flow of Information in a Man-Computer System

versus manual inputs should also be given consideration in the design of a given equipment. There should be a method for overriding any preselected priority sequence without changing the whole sequence.

The amount of information on a given display must be selectable by the human operator. If there is too much information or unwanted information mixed with the desired information, he must be able to remove some portions of the overall display or be able to expand a part of the display on a secondary display. He should also have control over selective portions of the display in order to view tabular or other information at the same time a graphical display is being produced.

All of these factors should be considered in the design of a given man-computer system with the main guide lines of the actual computer characteristics with which it is to operate.

The broad requirement for an input device is that an operator can readily adapt to it and can communicate his desires to the computer in an efficient manner. This requires that the device be designed using a minimum of controls, but with each control uniquely labeled and preferably able to call in a sequence of subroutines. The general purpose (stored program) computer is well suited for this type approach. By inserting an executive program into the memory, the control keys can be uniquely labeled to call out and execute desired portions of the program. Then, by changing the executive program, the functions of the controls can be changed. So by changing the labeling of the controls with an "overlay", many

special purpose control consoles may be simulated. An additional method for specifying information to a computer is that of allowing the operator to draw lines or symbols on a display surface or some input "sketch pad". An interpretive routine in the computer would then have to perform a pattern recognition, curve fitting, or other similar operation before taking action. One other desired control is closely linked to the display or output device. There must be a method for interrogating the computer about a point, a symbol, or an area on a display for the purpose of obtaining amplifying information about the interrogated portion.

The requirements for a display device are imposed by the user. Some of these are physical requirements based on the constraints of human reaction time and visual resolution, while others are based on clarity or recognition of information /3/. These have been listed with a brief explanation of each.

a. Selective display capability:

The computer can generate and hold in its memory a large amount of display information. The operator can intelligently use only a limited portion of the total supply of data at one time. For example, an aircraft controller may only be interested in traffic within a certain block of altitudes; so, he should be able to call in to the display only the representation of those aircraft within his volume of control.

b. Fast response to commands:

When asking for a new piece of information on a display or when dropping some outdated display, the response to the

command should be fast enough to allow continuity of thought for the operator. He should not have to wait for the command to be executed and the display changed.

c. Number and size of the display devices should fit the usage requirements:

In a large system several individual operators may be needed for specific tasks. This function may best be implemented by using a group of individual operator consoles working on data from a central computer and display generator. In some systems, a group of specialists may want to arrive at an optimum decision based on information on a central display. For this purpose, a large screen display is necessary with a possibility of inputting commands from one or more input devices.

d. The display should not flicker:

The retention of images by the eye is such that if a display is refreshed at a rate of about 30 frames per second, no flicker will result. The flicker of a display will be dependent on the storage time of the display elements. For example, if a long persistence phosphor is used in a cathode ray tube display, the refresh rate requirement is reduced, but the time required to change the position of any point on the display or the whole display is determined by the decay time of the phosphor. This decay time is dependent on the initial intensity of the display.

e. Resolution of the display should be greater than the resolving power of the eye:

The eye can discriminate parallel lines separated by

intervals equal to the line width to a value of 70 lines per degree. So for a single operator console, if the display surface is considered to be the base of an isosceles triangle and the eye to be the apex of this triangle (actually an isosceles cone), approximately 50% of viewing angle is included. This dictates that the display should have at least 2,000 "bins" for unique storage in each direction. To place this into a digital representation for computer generation the resolution should be at least 11 bits.

f. The contrast and brightness should be such that under ambient light conditions, the operator will not be subject to eye strain:

The intensity difference between background and information should be on the order of thirty to one for normal usage. If the ambient light is high, reflections from the display surface tend to "wash out" this contrast. A cathode ray tube display console that is designed to operate in normal room lighting needs to incorporate a fast phosphor that can be raised to a high intensity level without producing an extended decay time.

g. Accuracy and distortion should be reduced to an acceptable level:

In any display system, the ideal resulting display would have perfect registration and focus at all points of the display. This goal is rarely, if ever, attained due to hardware considerations. For example, in a cathode ray tube display there is definite defocusing effect at the edges of the tube as the path length of the electron beam is longer. Also, the voltages to pro-

duce the desired deflections in an electrostatic deflection tube (or conversely the current to produce deflections in an electromagnetic deflection tube) do not vary linearly with the distance from the center of the tube /4/. This leads to the use of compensation circuits in the control circuitry which can reduce these conditions to an acceptable level.

h. The coding should allow for a variety of presentations:

The requirements for flexibility encompass such ideas as color, size, shape, intensity, position and orientation. And blink rate as a means of attracting attention. Most displays require a set of symbols for normal usage. These would be numbers, the alphabet, and any frequently used symbols. In addition, a method of generating lines should be included for forming special symbols or line drawings. These "vectors" should allow for blanking portions of the length while proceeding along a given direction to enable the further coding of lines into dashed lines.

i. The format for the display should suit the usage requirements:

Some examples of formats are textual, tabular, graphical, situation or overlay map plus defining symbols, line drawings and diagrams, patterns of symbols to show complex situations, and pictorial symbols to show the status and condition of remote elements. The general classification can be termed either fixed or free. The fixed format is considered to be a textual or tabular type where automatic incrementing and positioning of symbols is accomplished on a set of constraints mechanized into the hardware.

The free format is usually implemented through a program control feature which must be generated in the computer.

The number of operators and/or viewers of a man-computer console has a direct bearing on the requirements as has been previously noted. For group displays, optical projection and electroluminescent panels have come into usage as the size of direct view cathode ray tubes are limited by deflection techniques. Examples of group displays have been discussed in recent publications /5, 6/. This thesis will discuss only single operator, direct view, non-colored cathode ray tube displays.

2. Techniques for Man-Computer Communication

The methods available for producing commands to a computer are largely dependent on the type computer being used in the system. For normal communications the computer is in control of the data lines, and the executive program must sample the possible inputs at "programmed" time intervals. For priority communications, the operator should have the ability to interrupt the computer and insert the necessary commands. The nature of any input to the computer is one of a digitally coded bit pattern dependent on the setting of switches or digital encoders, and the initiation of a command switch. A good example of this type communication is the console typewriter which can be used for input and output. An exception to this straightforward input technique is that of employing a "sketch pad" in which the input takes the form of movement of a probe over a display or an analog surface. In these cases, the computer must sample the allowable surface at a rate fast enough so that normal motion of the probe by the operator generates a smooth input of coded positional values corresponding to the desired lines being traced by the probe. In the case of a direct view cathode ray tube, the probe is a light sensitive photo-diode, and the computer program must display a raster of points about the last recorded position of the probe. The new point is recorded as a feedback of information of the position in the raster which coincides with the probe.

In order to produce a visual display on a cathode ray tube surface from a computer output, a certain amount of decoding and

processing must accompany each computer word. Principle requirements by the display device for each piece of information displayed are: (a) positional information, i.e., X and Y or ρ and θ with respect to some reference point; (b) coded information specifying character or line type, intensity, and size of symbol or length of line. The display circuitry must be able to decode this information and convert its meaning into the necessary deflection and intensity signals to produce the desired symbol at the specified location.

The symbol formation signals must be superimposed upon the positional deflection signals. This can be accomplished by voltage or current summers in the analog deflection circuitry. The methods of categorizing the various techniques for symbol generators have been listed in recent publications /7, 8, 9/. These are dot pattern, scanning raster, waveforms or strokes, and shaped beams.

In the dot pattern method, the symbols are made by positioning the beam to a sequence of positions defining the symbol. At each point in the sequence the beam is unblanked. The result is a group of dots oriented to form the desired symbol. The formation may use a cell of computer memory for each point displayed as in the PDP-1 console display /10/. This method is limited in speed to the speed of each memory cycle. An analog method for generating the dot pattern has been devised which makes use of resistor networks /11/.

A combination of scanning and the dot method are used by the Laboratory for Electronics in their SA-1 symbol generator. For this method each symbol in the set is represented by a selectable

matrix of magnetic cores. Each core is located at a position where a dot is to appear in the character. The matrix is scanned by rows while the beam in unblanked as a function of the cores.

A variation on the core scanning system is the VIDIAC /12/. Each symbol is again represented by a selectable matrix of magnetic cores. In this generator, the cores are positioned so that they make a double outline of the desired character. The selected matrix is then scanned by rows, and alternate cores turn the beam on and off. This causes the figure to be made up of a group of parallel line segments.

The scanning method of forming characters can be implemented by using flying spot scanner techniques /13/. In this method a fixed size scanning raster is moved to a spot on the generator tube which coincides with the desired character on a symbol mask. The portion of the beam that goes through the mask is focused on a photomultiplier, and this signal is amplified to control the intensity grid of the display tube. The scan pattern must be superimposed on the positional information for deflection signals. The combination of intensity and deflection produces the desired symbol on the display.

The stroke method has been used with much success in the "Calliscope" of Lincoln Laboratories /14, 15/, the symbol generator of Strand Engineering Laboratory, and the symbol generator of Data Display, Incorporated. The methods of deriving the deflection and intensity signals for each of these techniques vary considerably, but the results achieved are the same. The symbols are formed by

unblanking the beam at a starting point for each character and then moving the beam while it is unblanked. Some complex symbols require multiple unblanking and blanking during the formation period.

The shaped beam method is used extensively in the military display systems (SAGE and NTDS). The basis of the system is the "Charactron" tube /16/. The tube has a character matrix within the tube envelope. The character desired must be selected by positioning the beam to the associated figure in the mask by a small electrostatic deflection system. The beam is purposefully defocused to obtain a large cross-sectional area, and the shaped beam that gets through the mask is in the outline of the selected symbol. This shaped beam is then magnetically deflected to the desired position on the display surface.

A comparative analysis of these systems has been accomplished by Lowe, Sisson and Horowitz /7/. Two systems not included in this analysis are the "Strand" generator and the "DDI" generator. The respective times for generating a symbol with these systems are 40 and 6.6 microseconds. These rates of 25,000 and 150,000 characters per second compare very favorably with the other systems.

In addition to computer generated displays on cathode ray tubes, a common method for the computer to convey information to an operator is through coded and labeled lights. These are extremely easy for a computer to initiate, and providing the meaning is clear, can be an economical and efficient way for the computer to alert the operator. The main drawback for this technique is the relative inflexibility of the feedback and the possibility of

operator confusion if there are an excessive number of lights on the control console.

B. Design Specifications

The technical requirements for an advanced design digital control display console for the Digital Control and Automation Laboratory were stated as follows:

> This unit will provide character and symbol display facilities together with provision for direct display of radar video signals. In addition, it will function to provide for communications between an operator and a central computer.[1]

A research and development contract[2] was subsequently awarded to Data Display, Incorporated for the design and construction of the unit which has since been designated as the DD-65. The author worked in conjunction with Mr. Gene Grashorn of Data Display, Incorporated to specify and design this equipment. The remainder of this thesis will be devoted to the actual design of the DD-65.

The system requirements are dictated by the equipments that are to be controlled by or input to the DD-65. There are three distinct modes of operation inferred by the requirements:

a. To input radar information and to provide for (1) display of the video in a PPI format and (2) digitizing of any video return which may be determined to be a target by a detection unit so that the computer may act upon the information.

b. To allow the operator to enter information into the computer.

c. To allow the computer to present data to the operator in the form of symbols on a cathode ray tube or by drawing attention to certain input keys by a system of lights.

[1] [illegible]. L. Cotton, Technical Requirements Summary, Digital Control and Automation Laboratory, pp. 1, Feb., 1960

[2] Navy Contract NObsr 85678

The following radar units currently installed are to act as inputs to the system:

AN/SPS [illegible]

AN/SPS 8

AN/SPS 12

AN/SPS 26

These radars are installed in the main radar laboratory, and the following information must be made available for use in the D -65.

a. Azimuth information

b. "Main bang" or time of pulse transmission

c. Video return signal which will have any targets along with noise introduced in the process.

d. Height information in the case of the SPS 8 and SPS 26.

This analog information must be converted to digital information for display and further transfer to the digital processors.

The digital computers incorporated in the system are a large scale scientific computer, the Control Data Corporation 1604 /17/ and a small data processor, the Control Data Corporation 160 /18/. These computers communicate with external equipment by parallel data transfer lines which are controlled by a sequence of control signals. Also, an essential part of the system is the Control Data Corporation 1607 magnetic tape system which contains circuits for a "Satellite" operation between the 160 and the 1604 /19/.

In order to perform an output from the computers to one of a number of peripheral equipments, the following sequence must be performed:

a. Communications established with the desired equipment (exclusive of all others) by a coded select signal proceeded by a sense signal to determine if equipment is available.

b. Data transferred to output lines, and a signal output ready is sent to all peripheral equipment.

c. The selected equipment (only) recognizes the ready and accepts the data, and at the same time sends an output resume signal back to the computer.

d. The computer, upon receipt of the resume signal, then drops the data and ready signals and prepares for the next word transfer, if any, or merely continues on the internal program.

In order to perform an input to a computer from an external equipment, the computer program must be written so that it looks to see if any equipment has data ready for input. This must be done by coded sense responses which must be built into the peripheral equipments. The computer, upon recognizing the source and the presence of an input word, then sends an input request signal which signifies that it has accepted the data and allows the equipment to drop the signals for its data lines. This sequence must be repeated for each data word entry.

In the 1604 an additional input mode has been utilized. This is the interrupt mode. This interrupt mode must be preselected by a select code in the program. If the selected interrupt occurs during the program, the program sequence is halted at that point. The address at the time of the halt is inserted into the address portion of the upper half of word number seven of the computer mem-

ory, and a jump is made to execute the lower half command of word number seven (note that the 1604 is a single address, two command per word computer /17/). The memory cell number seven should be set up previously to process the interrupt. This coding should place unconditional jump commands in both halves of the word and the address of a prestored subroutine in the address portion of the lower half of the word. This subroutine must be written so that it ends with an unconditional jump to cell number seven. Thus, after having been interrupted, the subroutine is entered, and after processing the interrupt, the control can return to the program step which was being processed at the time of the interrupt.

These then are the physical rules by which the DD-5 was designed to perform its functions of control and display.

Certain other considerations in the realm of flexibility, usefulness and realizability then served to dictate the method of using the basic criteria in the actual system design. These will be listed as a collection of engineering decisions and the reasoning behind them.

The display will have a self-contained memory unit. This requirement is set for the purpose of freeing the computers from constant usage in refreshing the displays. The requirement that the display be refreshed every 30 milliseconds in order to obtain a "flicker free" display is one that is set by the response time of the eye. This dictates that if the display were to display text of 5,000 characters at six bits per character, then the bit rate

would be 900,000 bits per second. The 1604, if only one channel is active, has a maximum transfer rate of about 50,000 forty-eight bit words per second or about 2,400,000 buffered bits per second. The 160 has a transfer rate of about 80,000 twelve-bit words per second or about 960,000 bits per second (unbuffered). Thus, it is seen that the 160 can just barely do the static display at the necessary rate, and if any change is needed in the display, as would be the normal case for moving radar targets, it could not maintain a steady display. The 1604 is not as critical as it has a buffered output, but it still would be taxed in its buffering capabilities if more than a single channel is being used.

The use of a self-contained memory also frees the 1604 from the control subroutines which must be returned to in order to restart a display cycle. This allows more program time for computations. (In a real time air traffic control system with mach one aircraft, the computation times are critical.)

The memory package chosen was a 1024 x 24 bit ferrite core memory, licensed from Control Data Corporation. The size was chosen to compromise between the 12-bit 160 and the 48-bit 1604. The cycle time of the memory is 6.4 microseconds which is less than the 6.8 microseconds required to display a character. This allows a new memory cycle to be completed while the last character of the previous word is being displayed. Thus, for all characters to be painted, the total time involved is:

(6.8 microseconds per character) (4 characters per word) (1024 words per cycle) $\cong$ 28 milliseconds

The difference between the [illegible] milliseconds maximum and the [illegible] milliseconds required for an uninterrupted cycle allows five milliseconds for updating the data each cycle without inducing a flicker.

<u>The intercomputer operation must be selective.</u> In the physical layout of units the Control Data Corporation 1604 and the Control Data Corporation 1607 magnetic tape system are located in the U. S. Naval Postgraduate School computing center on the first floor of the Engineering Building. The Digital Control and Automation Laboratory is located on the fifth floor directly above the computing center. The DD-65 and the Control Data Corporation 160 of this system are to be located in that laboratory. Usage requirements dictate that the 1604 will not be available for use at certain times (pending the incorporation of a parallel processing monitor program). This requires a lockout be available for the 1604. Also, the 160 may be required to do full time processing of radar data for the 1604, and the data flow should be via the 1607 satellite system (1607) independent of the DD-65 system. So a 160 lockout is required. The result is the incorporation of a selective mode for using the system.

a. 1604 only (160 locked out)

b. Both (both computers may establish communications with the DD-65.)

c. 160 only (1604 locked out)

This is realized by a mode switch on the logic chassis.

<u>The basic format for display information should be sequential and the display should include vectors as well as characters.</u> The

requirements of a display to designate "where" and "what" for each piece of information displayed would at first seem that a format should be as follows:

X position	Y position	information

The normal usage of information, however, shows that there is usually a relationship between adjacent pieces of information. In the normal typed text or a drawn line that has been broken up into segments, the location of the next piece of information is incrementally connected to the previous one in some manner. The special case would then be taken as the carriage return for the typed text or the end of a line segment in the above examples. So only at these positions would an absolute location be required.

In the case of characters, the normal mode is to increment from left to right. This mode, along with an incrementing from up to down, has been included in the design.

In the case of vectors, several methods were examined. The generation of the vectors is to be under computer control so that any format using simple computations could be used. The following were the three possibilities:

a. Given a starting position, let the computer specify a completely variable ΔX and ΔY.

b. Given a starting position, let the computer specify a limited number of ΔX and ΔY in a coded format.

c. Given a starting position, let the computer specify ΔX and ΔY in 45 degree increments in coded format for a limited number of lengths.

Methods a. and b. both require adders or variable length incremental counters in their construction. Also, method a. needs a completely variable intensity compensation over the line length variations. Method c. needs incremental up and down counters only, but needs counting rate changes and intensity compensation for each length of line to be drawn.

The accuracies of methods a. and b. are greater, but they sacrifice packing density, and they require a greater amount of hardware to construct.

Using this criteria (also keeping a six-bit coded vector package to be compatible with the character coding size), the design incorporated was that of method c., but allowing for an extremely short vector so that the error could be minimized if the accuracy was needed. The use of incremental counters also makes easier the sequential designation of vectors for forming continuous lines.

The requirement for both characters and vectors dictated that a bit be set aside in each string designator word for "mode". The details of display coding will be covered in detail in Chapter 6.

<u>There should be two display tubes, only one of which is a direct slave to the radar inputs.</u> Inasmuch as this system is in part being designed to allow investigation on various digital processing techniques in radar detection, the use for comparative displays is desirable. One display tube must be available to display video information at any time between the "main bang" and the maximum range time (if radar input has been selected). During this time, all display information from the internal memory must be

"locked out" [illegible] target. [illegible] limits the amount [illegible] that may be done on this tube. The amount is proportional to the amount of time between the [illegible] the [illegible] of the next [illegible].

The second tube is independent of the radar inputs and can be used to display processed [illegible] background maps and amplifying information (such as height, [illegible], etc.). This tube is always available to the memory cycle and can be used in conjunction with the direct radar display.

Future displays could perhaps be built utilizing dual beam electrostatic tubes[1] to remove the restriction on time sharing of radar signals and computer displays.

<u>The manual inputs should allow flexibility</u>. The system is designed to be used with a stored program computer, so a large measure of flexibility is accomplished through the use of stored subroutines. The method of calling in a set of subroutines from a magnetic tape library must allow for different sections of the library to be called in for different uses of the console. This is best handled by an overlay which, in addition to [illegible] to designate the overlay, can change the switch function [illegible] by having the function associated with each switch engraved on the overlay board.

[1] Electronic Tube and Instrument Div. [illegible], [illegible] - 11 ½ Inch Diameter, Dual [illegible], Electrostatic Focus and Deflection Cathode [illegible], [illegible]

In addition to the unique switches, there are a few functions common to all uses of the console. These are treated as a subset of the special overlay function switches, and together they are referred to as keyboard two.

The character keyboard is referred to as keyboard one. This keyboard is made up of all the standard numerals and alphabet, along with special characters to complete the keyboard. These keyboards and their coding will be given full treatment in Chapter 7.

Other manual inputs required are a range switch to control the displayed radar presentation and some method for locating and identifying points on the display. There are two common methods for accomplishing this function digitally:

a. Track ball

b. Photo electric light gun

In the track ball method, two shaft position encoders are placed at right angles, and a ball in contact with both encoders allows the operator (by rolling the ball) to position the encoders very accurately. A symbol will have to be displayed under program control whose center is located at the X, Y position given by the encoders. Thus, by calling for the program to display track ball, the symbol may be centered over any point of interest, and then by a second subroutine this information may be used to enter new information or find a memory cell which contains this point for purposes of changing the display.

The method of the light gun accomplishes the same purpose, but it is positioned by hand over a display, and then the light sensi-

tive circuit is energized and the portion of the tube face under the light gun is illuminated, a circuit can be made to extract the contents of that memory cell to find the position.

The light gun is faster, and its use is a more natural reaction, but for closely spaced points the track ball with its accuracy is easier to use. Based upon this reasoning, a track ball was used in the DD-65.

<u>The display should allow for an auxiliary output channel to dump radar data.</u> In order to obtain best utilization of the computers, i.e., to let them perform computations at a speed limited by the programs (without interruptions for storing data), an auxiliary channel to accept the digitized X, Y (and Z component with minor modifications) has been provided. A buffer memory unit and associated control circuits should be provided between the radar data, and the computer assigned to do the processing. The radar processing computer can then call for targets at its own rate. The buffer memory unit must have a fast access time in order to accept targets at the rate they are received from the radars. The access time needs to be on the order of [illegible] microseconds if no targets are to be missed. This requirement can be met by designing the buffer unit from standard flip-flop circuits. This is economically feasible as the word size is only 12 bits, and the number of storage words needed should be small.

4. Hardware Consideration and Mechanization of Design Procedure

In order to design digital equipments to have high component packing density and at the same time to allow for easy maintainance, the computer industry has developed the following technique. The circuits to be used are specified in terms of type (pulse or level signal) and speed of response desired. From these requirements, a family of circuits can be designed which are compatible and which, by interconnection, can perform the logical functions AND, OR, or NOT. These circuits are then placed on printed circuit cards either singlely or in small groups. The system designer then need only know the parameters and limitations of the family of logic cards in order to specify the interconnections necessary to design a particular equipment. The construction is then completed by wiring the interconnections on a chassis made up of logic card sockets. In this way all active elements are on the removeable cards to allow for easy replacement of a faulty circuit.

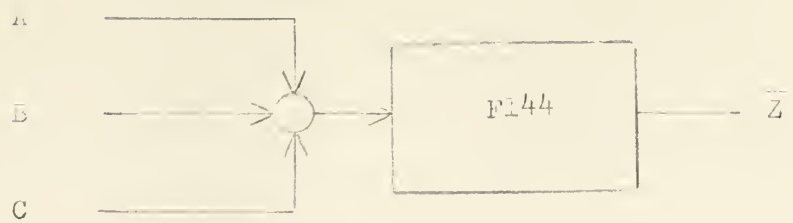
The logic card family used in the design of the DD-55 is mainly the Control Data Corporation type as described in their manuals /17, 18/ and reported on by J. F. Farrell /20/. These cards are designed to operate at clock rates up to five megacycles as level signal inverters. The switching delay is between 50 and 100 nanoseconds per card. Additional cards have been developed by Data Display, Incorporated for the special uses needed in displays. These are in two main categories: (a) Digital to analog conversion cards for driving the display beams and (b) a fast set of cards to work at about 20 mc for the display of digitized radar information.

he digital to analog part [illegible] will not be discussed in this chapter. The final logic card is completely compatible with the Basic Control Data Corporation family of cards, except for more stringent loading requirements.

The logic circuitry used is of the [illegible]. The basic circuit is an inverter with diodes on the inputs and may be used in such a way that (a) by connecting the outputs of two cards together at a single input of another card, a logical and is obtained or (b) by connecting the outputs of more than one card to a card with multiple inputs a logical or is produced. Figure 4-1 shows the two basic configurations and the symbology used to denote these functions. These basic functions may be combined to enable the designer to realize any complex logical function desired.

This type of logical building block does not readily lend itself to system design using an initial set of only logical equations which are to be simplified.[1] The reason for this is that the three level logic (and, not, or) built into each logic card is not easy to reduce mathematically. The method used is to specify the functions through diagrams. In this way conditional [illegible] may be built up without carrying along the necessity of digital manipulations that would be required. The technique used is important. By naming each inverter output once the design diagram is completed, an equation file can be written in terms of inputs to each inverter.

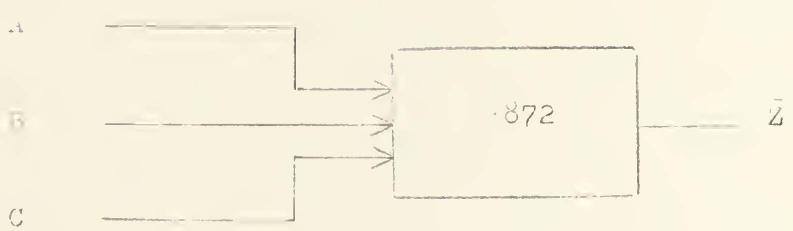
[1] A comparative system which can be simplified mathematically is the "Sheffer stroke" system.



$$Z = A \cdot B \cdot C$$

$$\bar{Z} = \overline{A \cdot B \cdot C} = \bar{A} + \bar{B} + \bar{C}$$

LOGICAL "AND"



$$Z = A + B + C$$

$$\bar{Z} + \overline{A + B + C} = \bar{A} \cdot \bar{B} \cdot \bar{C}$$

LOGICAL "OR"

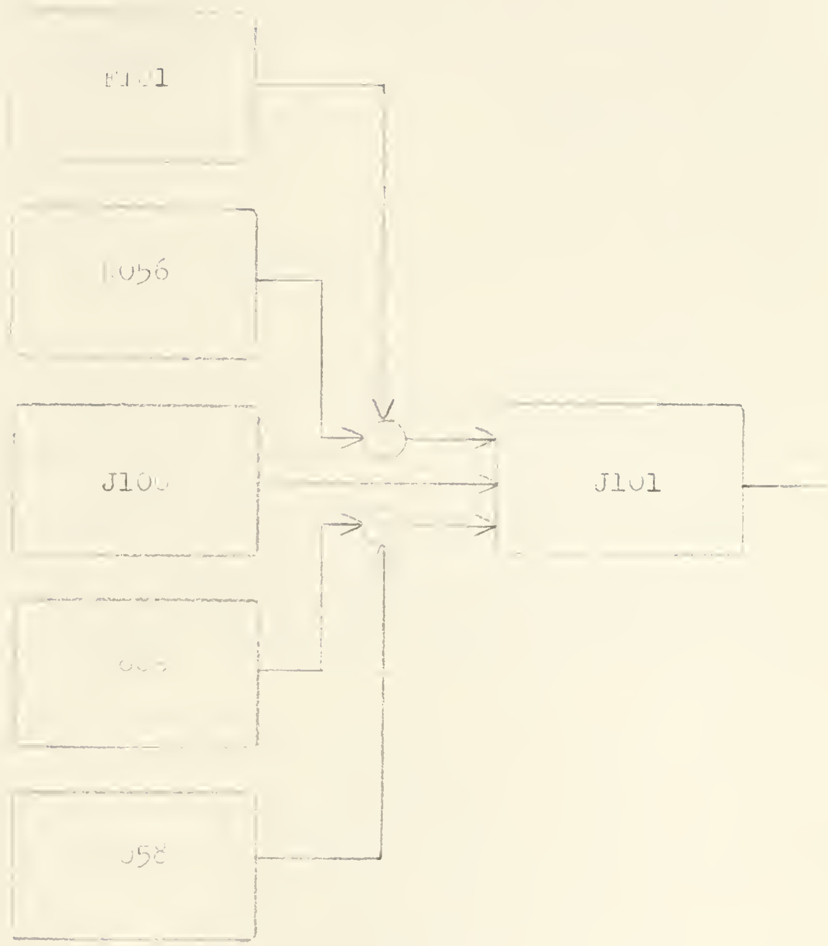
Figure 4-1
Logic Diagrams in Control Data Corporation Notation

This is shown in figure 4-2. As the equations are written in terms of inputs, no explicit statement of the inversion is used. When the design diagrams have been completed the individual card types may be assigned based on the number of inputs and outputs. Once the card types have been assigned, the total number of cards needed are uniquely known, and a chassis size may be chosen. In this line of cards there are up to three inverter sections on each card. The chassis layout can then be specified by assigning each card section a place on the chassis. This is done by assigning a row, a column, and a section to each inverter. The assignment is usually a compromise between obtaining the minimum lengths of interconnecting wire and keeping sections of the chassis grouped into areas of logical functions.

The last step in committing a logical design to hardware is the actual assignment and completion of the interconnecting wiring. The wiring constraints are set by the fact that each card socket has only two terminals per pin. This means that multiple AND signals have to be distributed along the wiring 'tree'.[1] (See figure 4-3). The task of assigning pin connectors in a manner to minimize wire length is very tedious, and the tedium of it tends to cause errors in the production of a wiring tabulation.

The desire to minimize the number of errors induced in the process between the design diagram and the wiring tabulation re-

[1]A "tree" is a <u>graph</u> having only one path between every two <u>nodes</u>.

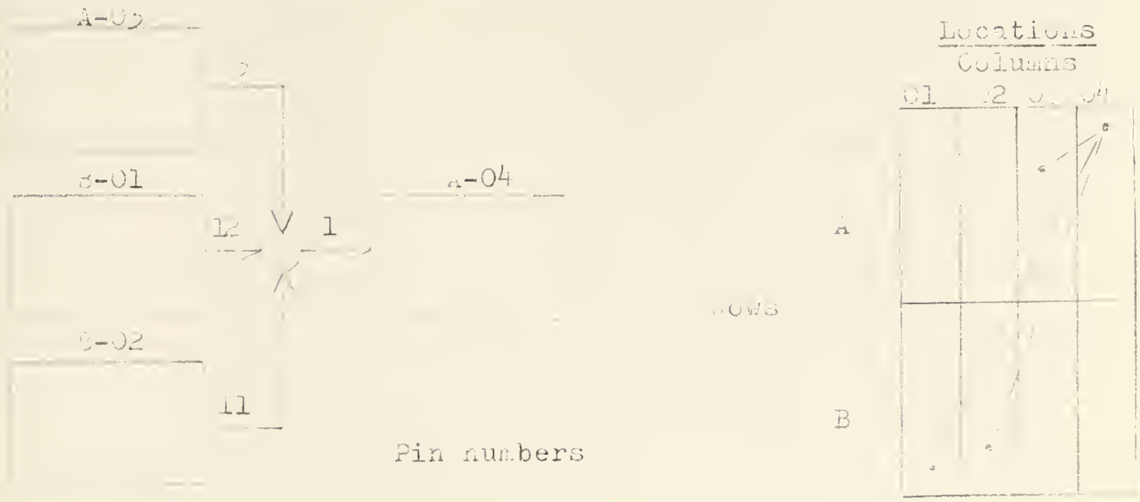


J101 = J100 + B089 K056 + F100 K05

Figure 4-2

Example of an Equation Written from a Logic Diagram

In order to wire an "AND" gate of more than two inputs, the following considerations are necessary:



Each connector has only connection terminals for two wires so that the interconnection similar to the depiction in the logic diagram is not possible. The resulting method is to build up a complete wiring "tree" by first accepting the smallest interconnecting wire and then building on this base until all "nodes" have been added to the tree.

Figure 4-3
Constraints on Chassis Wiring

sulted in a programming effort being made to mechanize some of the functions on the Control Data Corporation 1[illegible] computer. The computer has been assigned the tasks of formulating and printing out the completed file of equations and the final minimum wire length wire tabulations. Also, the program will assign card types, call attention to illegal equations, and give a tabular total of the number of cards by types required to implement the design. The necessary inputs are a set of "punched cards" which each such contain the equation for a single logic card section and a location for that logic card. The detailed report on usage of the program and an assembly listing of the program is included as Appendix [illegible] to this thesis. A sample of the input and outputs are shown in Figures 4-[illegible], [illegible]-5, 4-6, and 4-7.

The method for computing the minimum length wiring to connect a group of nodes is based on an algorithm by Loberman and Weinberger./[illegible]1/

This program was used in the production of the initial wiring data for the [illegible]-5. The total card count for the design is over 1500 cards. There are two separate chassis which made separate program runs necessary. The time required to compute the complete output listing was less than 20 minutes (exclusive of printing the magnetic tape off-line).

```
CHASSIS 1    DD 65
A000 = A001 + A002 V205 + A101 N009 + A201 N109          J1 J05A
A001 = A000 J842 + A003 V205 + N108 + GNDE               J1 J06A
A002 = A003 + A001 N800                                  J1 L04A
A003 = A002 + A000 N800 + GNDE + GNDE                    J1 J07A
A010 = A011 + A012 A003 V205 + A111 N009 + A211 N109     J1 J05C
A011 = A010 + A013 A003 V205 + N108 + GNDE               J1 J03A
A012 = A013 + A011 N800                                  J1 K03C
A013 = A012 + A010 N800                                  J1 K03A
A020 = A021 + A022 A013 A003 V205 + A121 N009 + A221 N109  J1 L08A
A021 = A020 + A023 A013 A003 V205 + N108 + GNDE          J1 L07A
A022 = A023 + A021 N802                                  J1 L06A
A023 = A022 + A020 N800                                  J1 L06C
A030 = A031 + A032 V215 + A131 N009 + A231 N109          J1 L08C
A031 = A030 + A033 V215 + N108 + GNDE                    J1 L09A
A032 = A033 + A031 N802                                  J1 L10C
A033 = A032 + A030 N802                                  J1 L10A
A040 = A041 + A042 A033 V215 + A141 N009 + A241 N109     J1 N08A
A041 = A040 + A043 A033 V215 + N108 + GNDE               J1 M08A
A042 = A043 + A040 N804                                  J1 M09A
A043 = A042 + A041 N802                                  J1 M09C
A050 = A051 + A052 V225 + A151 N019 + A251 N119          J1 N08C
A051 = A050 + A053 V215 + N118 + GNDE                    J1 N09A
A052 = A053 + A051 N804                                  J1 N07C
```

Figure 4-4
Sample of Input to Mechanization Program

```
        CHASSIS 1    DD 65

A000 = A001 + A002 V205 + A101 N009 + A201 N109
 J1 J05A   24    A003,    A001,

A001 = A000 J842 + A003 V205 + N108 + GNDE
 J1 J06A   14    T011,    H215,    A200,    A100,    A002,    A000,

A002 = A003 + A001 N800
 J1 L04A   22    T012,    T010,    A003,    A000,

A003 = A002 + A000 N800 + GNDE + GNDE
 J1 J07A   14    T013,    A021,    A020,    A011,    A010,    A002,    A001,

A010 = A011 + A012 A003 V205 + A111 N009 + A211 N109
 J1 J05C   24    A013,    A011,

A011 = A010 + A013 A003 V205 + N108 + GNDE
 J1 J03A   14    T013,    T012,    H215,    A210,    A110,    A012,    A010,

A012 = A013 + A011 N800
 J1 K03C   22    T011,    T010,    A013,    A010,

A013 = A012 + A010 N800
 J1 K03A   22    A021,    A020,    A012,    A011,

A020 = A021 + A022 A013 A003 V205 + A121 N009 + A221 N109
 J1 L08A   24    A023,    A021,

A021 = A020 + A023 A013 A003 V205 + N108 + GNDE
 J1 L07A   14    H215,    A220,    A120,    A022,    A020,

A022 = A023 + A021 N802
 J1 L06A   22    T001,    A023,    A020,

A023 = A022 + A020 N800
 J1 L06C   22    T000,    A022,    A021,

A030 = A031 + A032 V215 + A131 N009 + A231 N109
 J1 L08C   24    A033,    A031,

A031 = A030 + A033 V215 + N108 + GNDE
 J1 L09A   14    T002,    H225,    A230,    A130,    A032,    A030,

A032 = A033 + A031 N802
 J1 L10C   22    T003,    A033,    A030,
```

Figure

Sample of Output of File of Equations

U S NAVAL POST GRADUATE SCHOOL   DATA PROCESSING LABORATORY

COMPILATION OF CARD ASSIGNMENTS

CARD TYPE	NUMBER OF CARDS
11	1
12	NONE
13	NONE
14	210
15	1
16	36
31	NONE
32	NONE
33	NONE
21	81
22	204 1/2
23	17
24	29
01	21
61	NONE
62	NONE
S36	3 2/3
S04	NONE

Figure 4-8
Sample of Card Compilation

U S NAVAL POST GRADUATE SCHOOL   DATA PROCESSING LABORATORY

INTER CARD WIRING TABULATION

	ORIGIN	DESTINATION	DESIGNATIONS	WIRE LENGTH
*	J05-01	J06-12	A000 TO A001	3 INCHES
*	L04-06	J09-12	A002 TO V205	6 1/2 INCHES
	J05-02	J09-12	A000 TO V205	3 1/2 INCHES
*	J05-03	I03-12	A000 TO N009	3 INCHES
	I02-12	I03-12	A101 TO N009	1 1/2 INCHES
*	J05-04	H05-06	A000 TO A201	7 INCHES
	H05-06	H12-06	A201 TO N109	4 INCHES
*	J06-01	J842	A001 TO J842	31 1/2 INCHES
	J06-01	J05-06	A001 TO A000	2 INCHES
*	J06-02	J07-12	A001 TO A003	3 INCHES
	J07-12	J09-11	A003 TO V205	2 INCHES
*	J06-03	L01-06	A001 TO N108	8 INCHES
*	J06-04	GNDE	A001 TO GNDE	32 INCHES
*	L04-01	J07-11	A002 TO A003	6 INCHES
*	L04-02	J06-11	A002 TO A001	6 INCHES
	J06-11	J08-12	A001 TO N800	2 INCHES
*	J07-01	L04-05	A003 TO A002	8 INCHES
*	J07-02	J08-11	A003 TO N800	2 1/2 INCHES
	J07-02	J05-05	A003 TO A000	2 INCHES
*	J07-03	GNDE	A003 TO GNDE	32 INCHES

Figure 4-7
Sample of Wiring Tabulation

5. Radar Conversion Unit

The system must perform the two separate functions previously described in Chapter 3, i.e., (a) that of direct display of unprocessed video on a digital raster on a display tube, and (b) that of making available to the computer the digital information on a radar return if it is a possible target.

The requirement of a real time radar display places a restriction on the use of the display for computer generated information. The portion of time between start of sweep and the maximum range to be displayed must generate a signal to lock out any memory references to the display. As a result of this restriction, the system has been designed to include two separate display tubes so that one is always available for computer generated display information. The normal display information in the memory is directed to the designated display tube. The tubes are designated "0" for left and "1" for right for purposes of coding commands. The choice of which tube is to present the display is controlled by the use of the tube designator bit in the coding structure which will be discussed later. This "tube bit" controls the intensity grid of the designated tube by enabling the "unblank circuitry" to turn on the electron beam. Also, it gates the condition which [illegible] the display deflection signals to the designated tube. When radar video information is desired, the range switch is placed to the appropriate range. The receipt of a "main bang" from the radar sets a flip-flop whose output is used to remove control of the "0" tube from the internally generated display information (see Figure [illegible]). The

"set" output of the flip-flop "enables" the X and Y digital radar counters to input to the position registers of the digital to analog converters. The "set" output also "disables" the output of the computer generated display information, even though tube "O" may be designated to display some information while in the radar mode. When the designated maximum range has been reached, a signal is generated which "resets" the flip-flop. Thus, the internal display information can now be displayed on tube "O" until the next "main bang".

The range switch settings are shown in Figure 5-1 along with the time required by the radar to display each beam. This is based on the propagation rate of radar signals being 12.35 microseconds per range mile. The radar characteristics of the unclassified radars to be used with the system are shown in Figure 5-2. The remainder of the table in Figure 5-1 is a listing of the proportion of time remaining for inserting computer generated displays to the total amount of time possible. This information should be used when writing system programs to superimpose target information over a radar display. For example, if using the SPS-8 with the pulse repetition frequency set to [illegible] cycles per second and the range switch set to 64 miles, the availability of tube "O" to the generated display is 66.4% of the time. This indicates that the information should be written into the memory at two places to insure that it will be displayed. This technique of time sharing limits the amount of information that can be superimposed on the longer ranges. The SPS-26 places a slightly more stringent set of re-

[illegible] Switch Setting in [illegible]	Radar Display Time Requirements in Micro-seconds	Ratio of Time Available for Display			
		S P S - 8		[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	.508	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]			[illegible]	[illegible]

Figure 5-1
Comparison Table of [illegible]

	[illegible]	[illegible]-12	[illegible]
Horizontal Beam Width (in degrees)	.5	3	.5
Horizontal Rotation Rate of Antenna (in revolutions per minute)	5 to 1	[illegible] to 15	1 to 10
Vertical Beam Width (in degrees)	[illegible]	[illegible]	[illegible].1
Azimuth Information Available	1:1 speed synchro	1:1 speed synchro	1:1 speed & 36:1 speed synchro
Peak Power (in kilowatts)	50[illegible]	500	[illegible]
Pulse Width (in microseconds)	4	4	[illegible]
Pulse Repetition Frequency (in cycles per second)	150	[illegible]00	[illegible]
Expected Range (in miles for 1 square meter target)	[illegible]	52	[illegible]

Figure [illegible]-2
Characteristics of Radars to be Used in the System

quirements on the display for time sharing than any of the unclassified radars.

The method of generating the radar sweep requires accurate azimuth information in the form of a shaft position from the radar. This shaft motion drives a digital shaft position encoder whose outputs are sine ϕ and cosine ϕ. The outputs have an accuracy of ten magnitude bits plus a sign bit. These quadrature values are then "multiplied" by a series of range pulses in such a manner that counters being driven by the multipliers hold the results $R(\text{sine } \phi) = Y$, and $R(\text{cosine } \phi) = X$. When the range counter reaches its maximum value as determined by the range switch, the range counter is cleared, and the X and Y counters are then disconnected from the digital analog converters by the "enable radar" flip-flop previously described.

This technique then describes a radar display raster of the form shown in Figure 5-3. There are 2,048 separate "bins" in X and in Y corresponding to the 11 bits. This gives a possible accuracy of $\pm$ 1/4 nautical mile on the 256 mile range with possible accuracies increasing to $\pm$ 7.9 yards on the four mile range. The actual accuracy of the video display without a video processor incorporated to use only the centroid of the radar return is mainly limited by the pulse width of the radar used. The pulse widths range from one to four microseconds (see Figure 5-2) with a resulting possible error of approximately $\pm$ 1/12 mile to $\pm$ 1/3 mile.

The heart of this system is the range counter and the oscillator driving the counter. The clock frequency required to obtain

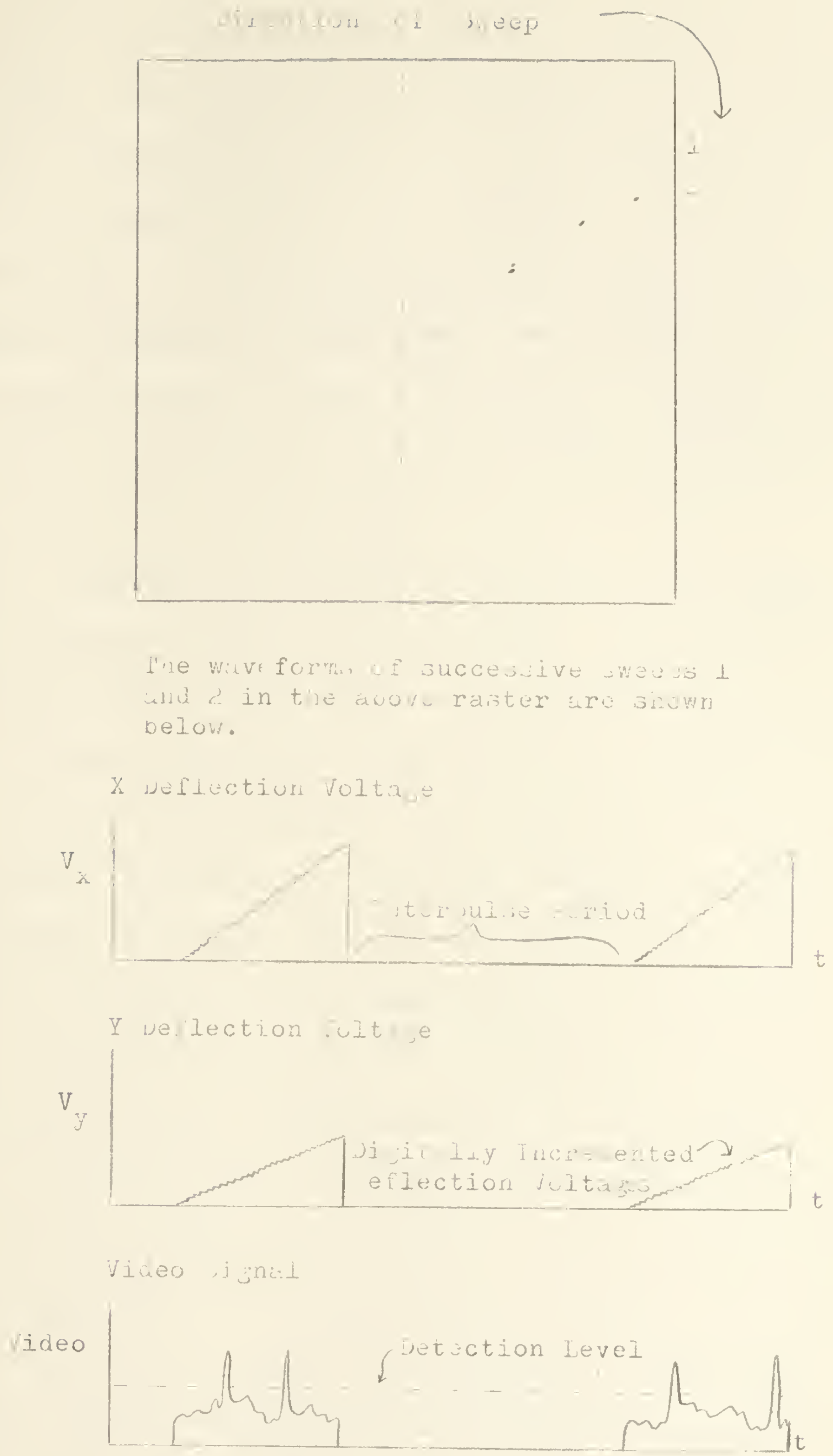


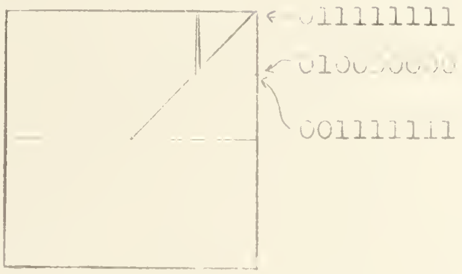
Figure 3-9 Example of the Digital Raster Produced by the Radar Scan

the accuracies needed is 20.72 [illegible]. The range switch then enables different bit positions of the counter to trigger the rate multiplier which results in full scale deflections for the chosen range. The radar section of the logic is the unit that determined the need for the new series of fast cards discussed in Chapter 4. The switching times of these logic cards were required to be much faster to reduce spikes in the radar video raster caused by the carry pulse in the counters when the most significant bit changes. (See Figure 5-[illegible]) These spikes (or "blivets") should be reduced in width enough to be insignificant by the fast cards.

The requirement of 11 bits of accuracy for the azimuth information requires accuracy to 0.176 degrees. The azimuth information available from the radars is in the form of 60 cycles per second synchro signals. The SPS-8 and SPS-26 have two-speed synchro systems which have an accuracy well within the 11 bits specified by the encoder. The SPS-6 and SPS-12 have only a one-speed synchro system which could have a maximum accuracy of about 0.3 degrees from the components. It is evident then that the available accuracy of bearing information is not quite precise enough for the system requirements. One other problem in this system is that the torque and inertia loads of the shaft position encoder require a high gain servo-system to drive the encoder. In order to furnish the maximum accuracy at suitable power levels to the encoder for each of the radar inputs, it was necessary to convert the individual radar synchro outputs to a single speed, high accuracy synchro output from the radar switch panel. The converter to be used for

The condition exists when a digital increase of one increment in the lowest order bit position causes a carry bit in the higher order bit positions. For example: for a change of the Y counter from 00111111 to 01000000, two possibilities may occur if the circuits concerned have a large difference in rise times.

1. The carry bits may be too fast resulting in the value of 01111111 for an instant.



2. The carry bits may be too slow resulting in the value of 00000000 for an instant.

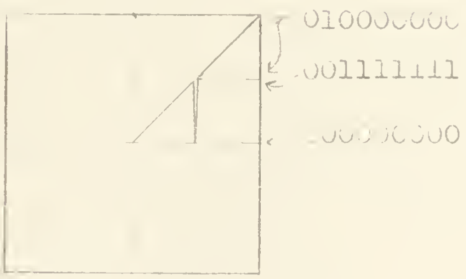


Figure 5-4

Formation of "blivets"

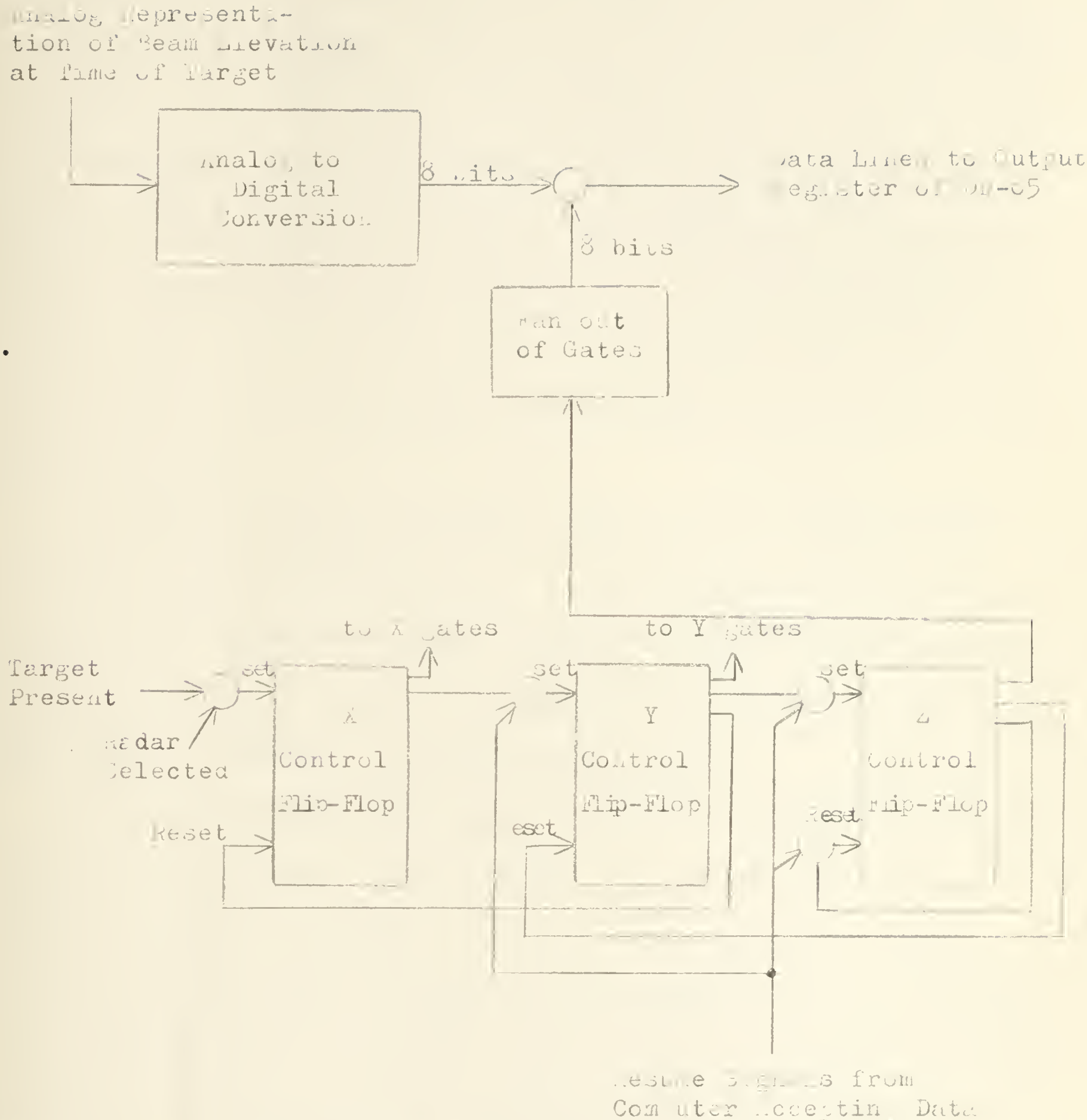
this is a "synchro amplifier". The unit is a standard Navy Supply servo system which accepts one or two speed synchro information and furnishes an accurate one speed synchro output. The output is specified to be a 400 cycle synchro signal for the long cable run from the Radar Laboratory to the Digital Control and Automation Laboratory. A commercial high gain servo system is to be purchased for driving the encoder unit in the DD-65.

The remaining requirement that the digital radar information be made available to the computer has been implemented by gating the 11 bits of X and 11 bits of Y to storage registers upon receipt of a signal signifying the presence of a possible target. This signal will be generated from raw video by an automatic detector which is designed to trigger when certain conditions are met, such as amplitude, slope of signal envelope, or combinations of time and amplitude. The study of optimum auto-detection units is to be one of the primary uses of this system. The detection units are to be fabricated on standard computer cards and locations for these circuits have been left in the operator's console of the DD-65. One type of detector has been designed and build by D. R. Briggs. It is a threshold detector with a voltage variable false alarm rate. This unit will be used on initial tests and is documented in a separate report /21/.

In the system design it was assumed that either the 160 or 1604 could be called on to process the radar data; so the X and Y registers were designed to be callable separately by the computers instead of packing them into a 22-bit word. This allows the 160

with its 1[illegible]-bit word structure to handle the processing load without excessive shifting of bits. The request by the computer for radar information sets a step counter which will sequence the X and then the Y information in a two-word group. The computer program must be tailored to this grouping by using a standard block input coding.

Provision has been left for extending the step counter to a three-word radar sequence. This was done to allow a third word, containing some measure of elevation angle or height information, to be sent to the computer for processing when using the SPS-26 or SPS-6. The output register of the DD-55 has eight bits set aside for this purpose. The implementation of this will entail an analog to digital conversion of the raw data into eight bits of digital information and provide a gate controlled by the third count of the step counter to enable the lines to the output register (see figure 5-5).



Present logic includes only the X and Y control flip-flops.

NOTE: Set side of flip-flop is upper side; reset side of flip-flop is lower side.

Figure 5-9
Necessary Logic for Addition of Height Information

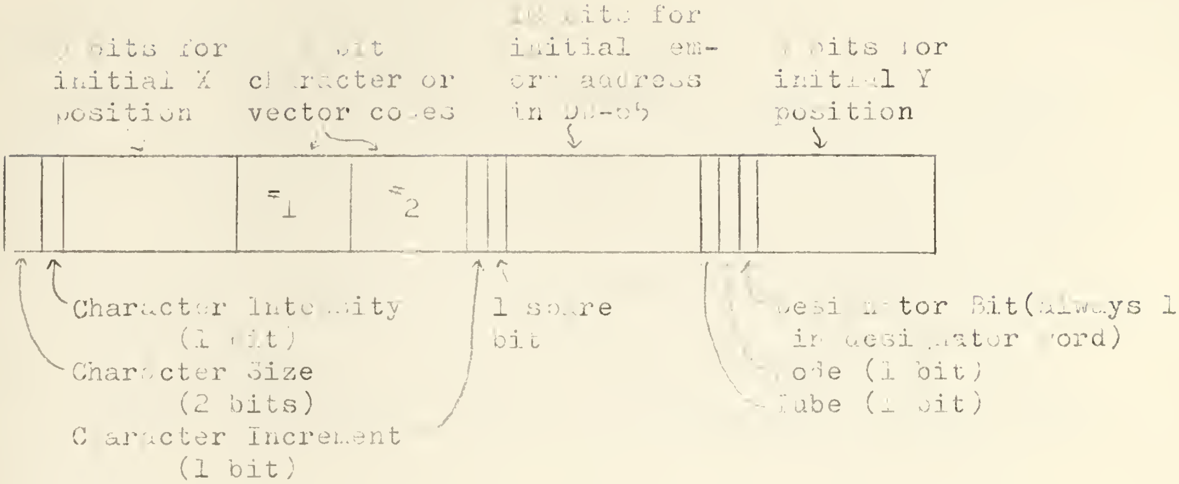
b. Design of Character and Vector Generators

The display of the actual characters and vectors is performed by cycling through the self-contained memory in the DD-65. This memory size is 1024 x 24. Therefore, in order to fill the memory with information, 512 words of 48 bits each would be required from the Control Data Corporation 1604 or 2,048 words of 12 bits each would be required from the Control Data Corporation 160. Any updating of information from the computers to the DD-65 breaks the display cycle, but saves the address of the next display word, and continues from the break address after the new information is read into the memory.

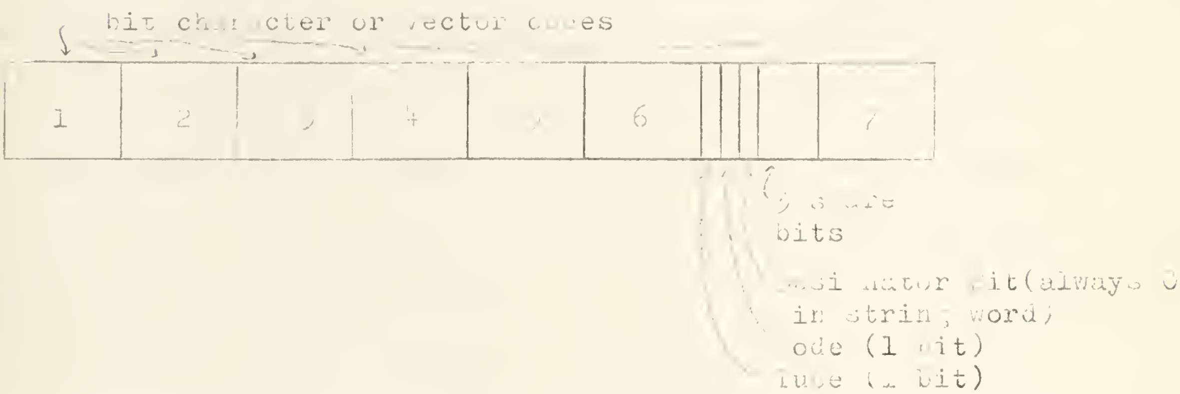
The basic length of the words needed by the decoding logic is 48 bits. This requirement is dictated by the fact that the number of bits needed for control information, position, and address are more than the 24 bits of the memory word. This then limits the total possible number of display words to 512.

As was mentioned previously, the formation of the characters or vectors are grouped into "strings". The first word of each string is called a "designator word". (see Figure [illegible]-1) This furnishes the control information to the decoding logic to prepare for displaying the information. Two characters or vectors can also be packed into the "designator word" to provide fast updating of a moving symbol. All following words up to the next "designator word" are considered to be string words. They can have up to seven characters or vectors packed into each word. The reason for using only seven of the eight possible symbols is the need to be able to

DESIGNATOR WORD (1-1[illegible] word or [illegible]-1[illegible] words)



SUBSEQUENT STRING WORDS



CONTROL CODES:

Mode: 0 - character (enables logic to decode the character information codes)

1 - Vector mode (enables logic to decode the vector information)

Tube: 0 - Display the stored information on left tube

1 - Display the stored information on right tube

X and Y positional information is formed by an eight-bit "absolute" magnitude code with a sign bit added to indicate direction from the center of the tube (0 sign bit is positive and 1 is negative). Initial memory address of DR-65 must be specified for each string by a 10-bit address code. The storage of consecutive words is incremented within the logic.

Figure 6-1 Programming Information for String Words

uniquely recognize the designator bit "D". Thus, the "D" bit must remain "0" in all string words.

In order to make corrections or update any part of a string, the whole corrected string must be read into the display memory. This is due to the incremental mechanization of the address counter. Only the designator word contains an address reference for the memory. Once a string of display words has been set up to read into the memory, the address counter is incremented as each 24 bits is accepted.

The designator word also contains the initial positioning information for the string. The initial position of the string is specified by nine bits of X and nine bits of Y. This allows a position to be selected to within 1/512 of the usable scope face. The usable portion of a 12-inch diameter tube is a square raster of about 8.5 inches. This allows the position of any symbols to be designated to within 0.0165 inches.

The choice of tube to display the information and the mode (i.e., choice of whether the information is a character or vector string) must be repeated in each word of the string. The appropriate coding for these are shown in Figure 6-1.

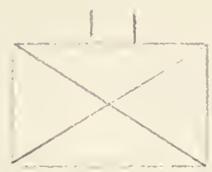
The vector mode and the character incrementing portion of the character mode use the same logical packages. These are a pair of nine bit position counters. The X and Y position counters are initially set to the position specified in the designator word for a string. The outputs of these counters drive the position registers of the digital—analog converters for the display tubes (see Fig-

ure 6-1). The counters are designed so that the contents may be counted up or down or not incremented depending on the control signals generated in the decoding logic. Thus, the amount and direction of beam movement is determined by the individual mode decoding circuits.

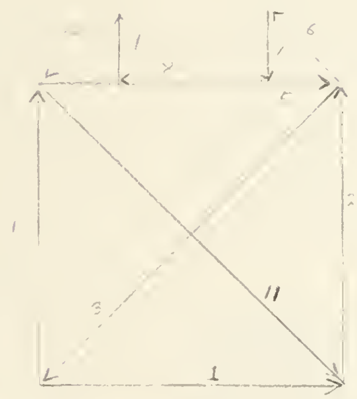
The vector mode requires only initial position information from the designator word. The formation of a line is started by unblanking the beam and then moving it a direction and distance as specified by a six-bit vector code. The beam is then "blanked" while the next six-bit vector code is brought into the decode logic. The sequence is then repeated until the next designator word is encountered. This technique produces a line by starting each new segment from the end point of the last (see Figure 6-2). The blank words between the end of any information and the next designator word causes no problem as the "O" code in either the vector or character mode does not unblank the beam even though the position counters may be incrementing.

The vector decode logic separates the six-bit code into a three-bit direction code, a two-bit size code, and an "unblank" bit. The direction code allows for eight possible directions which corresponds to 45^{o} increments in direction. The size code allows for four possible segment lengths. The unblank bit can be used to form dashed lines by allowing the beam to be blanked while still following a prescribed vector path. The vector codes are shown in Figure 6-3. The direction code determines the operation of the X and Y position counters, i.e., whether to count up, count down or

In order to depict the location of an infantry battalion on a military map, the following symbol is used:



To include this symbol on a map generated by the D[illegible]-[illegible]5, the following trace could be generated:



The sequence of necessary vector codes (see Figure [illegible]) to form the above symbol is:

(1) 110000
(2) 110010
(3) 11[illegible]1[illegible]1
(4) 110010
(5) 110001
(6) 000011
(7) 1[illegible]110
(8) [illegible]11[illegible]
(9) 1[illegible]01[illegible]
(10) [illegible]0101
(11) 11[illegible]111

Note: The starting point location must be given in the designator word.

Figure 6-2 Example of the Trace Produced by Vectors

Vector format (6 bits per vector)

3 bits for direction
2 bits for size
1 bit for intensity

Intensity Information

Code	Interpretation
0	No brightening of the beam
1	Normal intensity

Size Information

Code	Interpretation
00	X and/or Y coordinate deflection is 1/128 of full scale deflection
01	X and/or Y coordinate deflection is 1/64 of full scale deflection
10	X and/or Y coordinate deflection is 1/32 of full scale deflection
11	X and/or Y coordinate deflection is 1/8 of full scall deflection

Direction Information

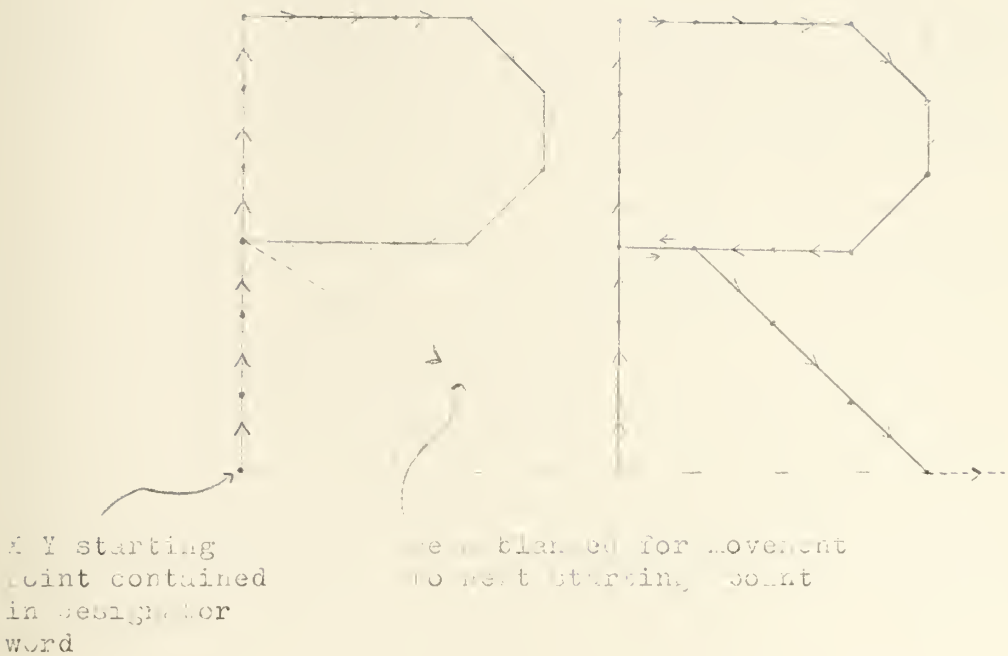
Code	Interpretation
000	Vector is drawn at an angle of 0° from starting point
001	Vector is drawn at an angle of 45° from starting point
010	Vector is drawn at an angle of 90° from starting point
011	Vector is drawn at an angle of 135° from starting point
100	Vector is drawn at an angle of 180° from starting point
101	Vector is drawn at an angle of -135° from starting point
110	Vector is drawn at an angle of -90° from starting point
111	Vector is drawn at an angle of -45° from starting point

Figure 6-3
Programming Information for Coding Vectors

not count. The length code determines when to stop incrementing the counters. The incrementing rate is 0.4 microseconds per pulse, and the number of counts must increase in proportion with the line length. The longest line length was included for the purpose of economical drawing of ordinates. One line, the length of the digital raster, can be packed into a string of two words. It is felt that the smallest increment will allow special symbols to be made up from coded vector strings without being incompatible with the normal character sizes.

The character decode logic is considered to be proprietary information by Data Display, Incorporated. The general technique is one of micro-positioning the beam in relation to a reference X, Y position on a 5 x 7 matrix. The logic is entirely designed from the basic inverter logic cards. The characters are formed by moving the beam and turning it on and off under a clock control whose pulses occur every 0.2 microseconds. The character rate is determined by the number of increments needed to trace the most complex character. For the symbol selection of the DD-65 the number of increments required is 33 pulses. This sets the time for display of one character at 6.6 microseconds. This time includes the incrementing of the reference position to the next character location (see Figure 6-4).

In addition to the initializing information required in the designator word by both the vector and character modes, the character mode requires some additional information on size and incrementing. A convenience intensity control bit is included to



Formation is on a 5 x 7 matrix with spacing generated by the matrix size being slightly smaller than the incrementing deflection.

NOTE: The incrementing information is contained in the designator word.

Figure 3-4
Example of the Trace Produced by Characters

allow [illegible] normal [illegible] of characters for [illegible] of superimposing data over a background or radar display. The format is shown in Figure [illegible]-1. The bit pattern of these information bits sets flip-flops which control these functions throughout the current string. The size selection is limited to only three out of a possible four as no need is seen for the large characters. The character size has a direct relation with the position increment length. As the vectors and characters use the same position counters, the character sizes were adapted to the increment lengths designated for vector lengths. The various codes for character control are shown in Figure [illegible]. The normal character sizes are the 32 or 64 per display width. The small size was incorporated to allow for possible future photography techniques which could allow large quantities of printed text to be permanently recorded for later projection. The direction of incrementing characters within a string is normally to the left to right as in a printed page, but for possible labeling of graphs or plots, a down increment has been included. This was easily incorporated as the [illegible] can be [illegible] into the minus side of the [illegible] counter for [illegible] complexity than required for [illegible] only into the plus side of the X counter.

Size Information (2 bits)

Code	Interpretation
00	Character size is 1/128 of full scale deflection
01	Character size is 1/64 of full scale deflection
10	Character size is 1/32 of full scale deflection

Incrementing Information (1 bit)

Code	Interpretation
0	Successive characters are incremented to the right
1	Successive characters are incremented vertically downward

Intensity Information (1 bit)

Code	Interpretation
0	Normal intensity
1	Brighter than normal intensity

NOTE: The usage of these character control codes is shown in Figure 5-1.

Figure 5-5
Character Control Codes

7. Design of the Input, Output and Control Functions

In order to commit the requirements of Chapter to hardware, a suitable set of rules in the form of logical circuitry must be designed to allow for the establishment of communications between the various units of the system, and the collection and transfer of data between these units.

The establishment of communications with the computers is accomplished within the standard structure of sense and select commands of the Control Data Corporation 160 and 1604. These commands and the control signals have been documented in the company manuals /17, 18/ and have been included as Appendix 2 to this thesis. All reference to command structures will be made in "octal" notation instead of the actual binary notation. The requirement that the computers can be selectively locked out of the system places an additional restriction on the decode functions. It was decided that in the individual computer operation modes (i.e., 160 only or 1604 only), the select codes for the other computer would be uniquely locked out. In the combined operation mode ("both"), the restrictions were lifted, and the computers can cross select to control the flow of information. For example, it is possible for the 160 to select an interrupt condition for the 1604 in this mode. The only arbitrary decision concerns the flow of manual input (i.e., keyboards, track ball and range switch). In the "both" mode all manual input selects are gated so that the data is input to the 1604.

The request for information or action by a computer is indicated by a 12-bit external function code being transmitted to all

peripheral equipment along with any control signals over their separate lines. From a study of all codes assigned to actual or proposed peripheral equipment for the computers, it was found that the 7XXX series of codes was not designated. This 7XXX series was chosen as the unique code series of the DD-65.

In order to continue further into the design of the control structure of the DD-65, it next became necessary to precisely define the various inputs and outputs and their inter-relationships.

The structure of the display words to be transferred from the computers to the DD-65 has been described in Chapter 6. These are the only data channel inputs to the system from the computers. The transfer of the "strings" of display information is to be by normal computer output blocks. The DD-65 must, then, have the provision for recognizing commands from the computers, to select this transfer, and to set up a "ready - resume" system of signals to control the input of the blocks of information. These two transfer channels have no restrictions set on them by other data modes of the system, but they should be mutually exclusive.

The digitized radar information is a sequence of words from the radar channel to one of three possible terminal equipments, i.e., the 1604, the 160 or the auxiliary channel. The sequence is controlled by a counter which successively gates in the 11 bits of X and the 11 bits of Y, and has provision for extending this to gate in eight bits of height information. These eight bits of elevation allow an angular resolution of about 1/4 degree. This sequence is triggered by an externally produced target pulse which

manufacturer from the view of the detection circuit. This input entails two levels of selection to be made by the select code used. These are: (a) The choice of one out of three possible terminations for the information and (b) the selection of accepting the radar information exclusive of all other inputs to the DD-65 except from the computers.

The group of manual inputs from the operator's console can only be directed to the computer assigned by the mode switch (as described in this section). This places the requirement for only a single input selection on the select code. The selection is to be exclusive of all other normal input selects.

There is one other unique input necessary from the DD-65 to the Control Data Corporation 160. This is the response to a "status request". This response should be selectable to the exclusion of all other inputs when the program on the 160 is checking for the occurrence of conditions at the DD-65. The response is coded into a one out of twelve response. In this way, if more than one recognizable condition has occurred, the response will include them, and it is up to the 160 program to check for the conditions. The "status response" selection is disabled when in the "1604 only" mode. Note that the 1604 operates the sensing of conditions of the peripheral equipment in a different manner. It uses a separate control signal to denote that the condition has been met.

To expand on the manual inputs, the following separate pieces of information are generated:

a. X track ball 9 bits

b. Y track ball   bits

c. Overlay   bits

d. Range switch   bits

e. Symbol keyboard (number 1)   bits

f. Control keyboard (number 2)   bits

The X and Y track ball information has been made separately selectable to keep the CDD-65 output register to less than 12 bits so that the same output register and usage rules may be used by both the 160 and 1604. The overlay and the control keyboard have been combined into a nine-bit output, as the method of interpreting the commands of the control keyboard is dependent on the overlay which should control the program package. The range switch and the symbol keyboard are treated independently.

The use of light feedbacks to the console operator (in conjunction with the control keyboard) dictated the need for additional select code requirements. These select codes are used to turn on or off any of the lights associated with the control keyboard. There is no restriction on the use of these selects as they have no inter-action with the inputs or outputs.

One other mode of operation to be incorporated is that of using the interrupt feature available on the Control Data Corporation 1604. These selections need not be unique or exclusive as the portion of the program entered when an interrupt occurs can be made to sense which of the selected interrupts has occurred.

A general diagram of the control function circuits is shown in Figure 7-1. A more detailed breakdown is given in Figure 7-2.

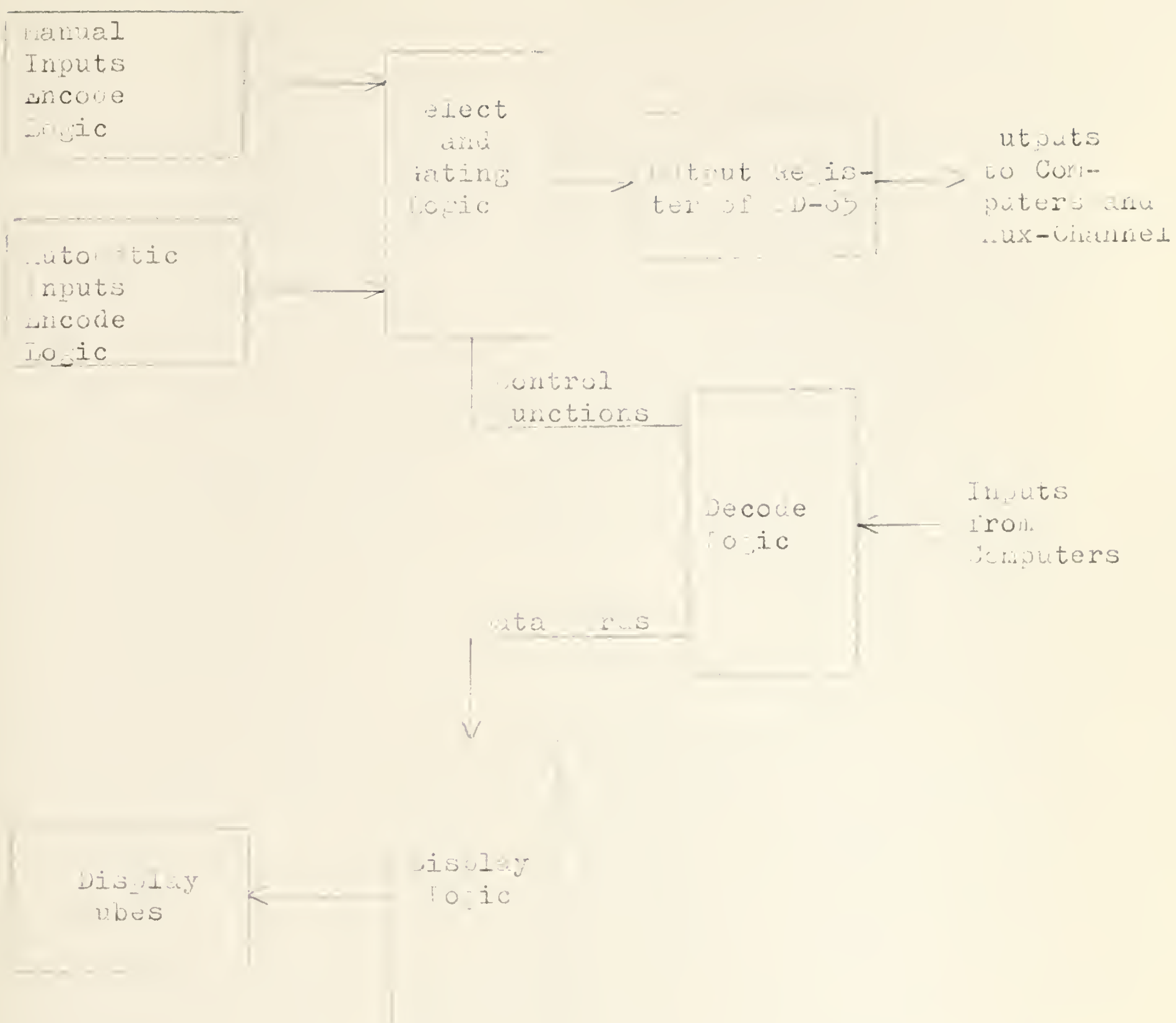


Figure 7-1
General Block Diagram of Control Functions

[illegible] to precisely define the necessary [illegible]. The [illegible] a maximum of 64 possible [illegible]. This is specified by the allowed six bits in the keyboard code. In order to determine the necessary number of symbols needed for keyboard number one (the symbol keyboard), a comparison was made of the symbol sets required for various programming languages. This comparison included the assembly programs [illegible] /[illegible]/ and [illegible] /[illegible]/, the business oriented compiler COBOL /24/, and the algebraic compilers [illegible] /2[illegible]/, [illegible] /26/, and JOVIAL /27/. In addition to the symbol set, it was also necessary to include a certain few editing keys. These are "carriage return", "tab", and "space". The choice of coding for the symbols was made using the criterion that [illegible] of the code would be desirable. The coding that evolved is an expansion of the basic "Binary Coded Decimal" (BCD) which is standard in most input and output equipments not having a provision for upper and lower case. The code "[illegible]" was not assigned an input symbol, but the key was included on the keyboard so it can act as an alternate space code. This allowed 6[illegible] symbols to be assigned to the remaining codes. The final assignment is shown in Figure 7-2. The physical layout of the keyboard was [illegible] to separate the two major functions of its use. A standard typewriter keyboard and a tabular type numeric keyboard were formed by making the key covers of a different color than the special keys around them. This should allow easier identification of these areas of the keyboard for more efficient usage. The 64-key keyboard was bought [illegible] com-

Symbol	Octal Code	Symbol	Octal Code	Symbol	Octal Code
∅	12	O	46	.	73
1	01	P	47	↑	[illegible]
2	02	Q	50	,	[illegible]
3	03	R	51	→	35
4	04	S	22	<	72
5	05	T	23	≥	37
6	06	U	24	≠	14
7	07	V	25	==	13
8	10	W	26	/	21
9	11	X	27	*	[illegible]
A	61	Y	30	+	60
B	62	Z	31	-	40
C	63	CR	76	'	16
D	64	Tab	[illegible]	[illegible]	[illegible]
E	65	Space	20	Space	00
F	66	}	52	∧	57
G	67	{	75		
H	70	[	17		
I	71	]	32		
J	41	(	34		
K	42	)	74		
L	43	:	15		
M	44	//	53		
N	45	;	77		

Figure 7-2 Symbol Character Codes

plete package. Additional logic was incorporated to make the unit compatible with the "ready - resume" signals of this system. The keyboard layout is shown in Figure 6-5.

The control keyboard (keyboard number two) is a collection of function designators. The proposed usage for them is for calling routines and subroutines for aid in console usage. This keyboard is also closely associated with the overlay and the light feedback features. There are three groupings of switches in this control keyboard (see Figure 6-5). The first group is a 20-switch matrix which is used in conjunction with the overlays. The functions performed by each switch are engraved on the plastic overlay panel which fits around the switches. The computer can illuminate selectively any switch or switches under program control to present a "guided" choice to the operator for his actions. The eight overlays available give a choice of system programs callable from a single library tape. The second group is a ten-switch unit which is also under computer control for light feedback. These are not associated with changeable overlays and are intended to perform functions which are common to all overlays. For instance, one of these keys could be labeled "display track ball symbol on left tube". The last group is a diamond of four switches which are intended to be used in editing symbols. They can be used to activate routines to move a marker over the face of the displays. This marker can be used to indicate the position for writing or erasing the next character. The movement commanded by these switches is intended to be incremental in nature as opposed to the "continuous"

nature of the two c ..li. These r keys are not associated with the computer controlled light feedback feature.

The coding of keyboard number two is made up from a diode matrix which was designed to use the minimum number of diodes. The coding of these keys is shown in Figure 7- . The depression of a key in keyboard two sets up a ready condition which is held until the computer samples the lines and releases the register. The overlay code is transmitted along with the control keyboard code when the input from keyboard number two is sampled. The overlay code is generated by the presence or absence of a contact post in the three bit positions of each overlay panel. This allows for changing the overlay code with a change of the overlay, and hence, to be able to change the labels associated with each of the 20 switches in the matrix.

The X and Y trackball generators are nine-bit shaft position encoders whose outputs are in "Gray Code" /20/. The outputs are converted to binary code for use in the computer. This coordinate information is always available and need only be selected by the computer to sample the value.

The radar display range switch is an eight-position switch. There are seven selectable ranges and an off position. The codes are shown in Figure 7-4. The switch has the dual function of controlling the radar video presentation and providing the computer with a measure of range correlation for making computations on target position. The entire operator's console is shown in Figure 8-5.

SWITCH POSITION	OCTAL CODE	SWITCH POSITION	OCTAL CODE	SWITCH POSITION	OCTAL CODE
1-A	01	4-A	31	8-1	61
1-B	02	4-B	32	8-2	62
1-C	03	4-C	33	8-3	63
1-D	04	4-D	34	8-4	64
1-E	05	4-E	35		
2-A	11	5-A	41		
2-B	12	5-B	42		
2-C	13	5-C	43		
2-D	14	5-D	44		
2-E	15	5-E	45		
3-A	21	6-A	51		
3-B	22	6-B	52		
3-C	23	6-C	53		
3-D	24	6-D	54		
3-E	25	6-E	55		

Keyboard [illegible] - Function Switch Designation

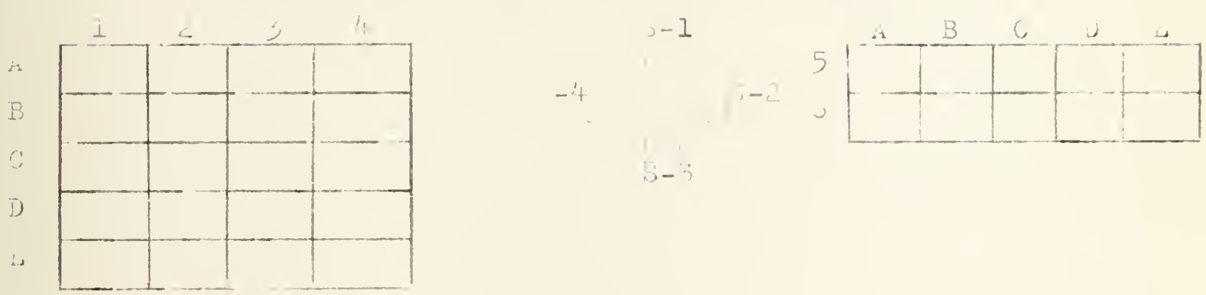


Figure 7-5
Function Switch Codes

SWITCH POSITION	OCTAL CODE
Off	0
4 miles	1
8 miles	2
16 miles	3
32 miles	4
64 miles	5
128 miles	6
256 miles	7

Figure 7-4
Range Switch Codes

Now that all inputs and outputs are defined, it is possible to assign select and sense codes, and design the logic. Two editing functions were added to the sense and interrupt functions. These were the keys "carriage return" and "tab" of keyboard one. These were included as special cases of keyboard one for the possibility of processing a word or a group of words on a functional command instead of processing single characters. The sense codes are listed in Figure 7-5. The select codes are listed in Figures 7-6 and 7-7.

All the function codes are in the 7XXX series. The primary decode is done by checking for the coincidence of a 7XXX and one of the external function signals from the computers. In the "both" mode of operation a time shared check is made of the external function lines from the 160 and 1604. The checking rate is rapid enough to return to sample each computer bit in the eight microseconds that the function pulse is present. Once the initial 7XXX is recognized, a pulse is formed which samples the lower nine bits of the code and sets the selected flip-flop (or in the case of a sense code for the 1604, allows an output pulse to be formed conditioned on the sense).

The ability to clear all the select flip-flops has been incorporated using the external clear lines of the computer in control (as selected by the mode switch). In addition to these possibilities, the "clear/start" control for the DD-65 memory will clear all select flip-flops. The overall diagram of the control logic is shown in Figure 6-2.

Sense Condition	1604 Sense Command Codes	160 Sense Response Codes
Keyboard no. 2 hit	[illegible]	[illegible]
Keyboard no. 1 hit	7104	[illegible]
Carriage Return hit	7110	xxx4
Tab hit	[illegible]	xx1x
Radar target present	7140	xx2x
Keyboard no. 2 not hit	7103	
Keyboard no. 1 not hit	7105	
Carriage Return not hit	7111	
Tab not hit	7121	
No radar target	[illegible]	
Keyboard no. 1 selected	[illegible]	xx4x
Radar to ABK selected	[illegible]	x1xx
Radar to 1604 selected	7002	x2xx
Radar to 160 selected	[illegible]	[illegible]
DD-65 from 1604 selected	7010	1xxx
DD-65 from 160 selected	7020	2xxx
Keyboard no. 2 selected	7040	4xxx

Figure 7-5
Sense Function Codes

[illegible]	[illegible] 1604	[illegible] 160	[illegible]
Select Track Ball X	7102	7102	[illegible]
Select Track Ball Y	7104	7104	[illegible]
Select Range Switch	7110	7110	[illegible]
Select Keyboard 2 plus Overlay	7120	7120	000VVV[illegible]
Select Keyboard 1	7140	7140	[illegible]
Select Keyboard 2 plus Overlay with Interrupt on Key-hit	[illegible]	[illegible]*	[illegible]
Select Keyboard 1 with Interrupt with Interrupt on Key-hit	7105	7105*	[illegible]
Select Keyboard 1 with Interrupt on Carriage Return	7111	[illegible]111*	[illegible] (C.R. Code)
Select Keyboard 1 with Interrupt on Tab	[illegible]	[illegible]*	[illegible] Code)
Select Radar Info to 1604 with Interrupt on Receipt of Target Pulse	7141	7141*	[illegible] (Future)
Select Radar Info to Auxiliary on Receipt of a Target Pulse	7001	[illegible]	Same
Select Radar Info to 1604 on Receipt of a Target Pulse	[illegible]	[illegible]*	Same
Select Radar Info to 160 on Receipt of a Target Pulse	[illegible]*	[illegible]	Same
Select 160 Status Response	[illegible]*	[illegible]	See Figure 7-[illegible] for 160 Status Responses
Select n-Word Memory Update from 160	[illegible]	[illegible]	None—See Figure [illegible]-1 for Obtaining Info.
Select n-Word Memory Update from 160	[illegible]*	[illegible]	None—See Figure [illegible]-1 for Obtaining Info.

On 160 only - all manual inputs to the 160; on 1604 only or both - all manual inputs to the 1604.

* Disabled selectively on 160 only or 1604 only - [illegible] switch position

Figure [illegible] - Select Function Codes for Control Functions

SELECT FUNCTION	SELECT CODE 1604	160
Select Light 1A-On	7202	[illegible]
Select Light 1A-Off	[illegible]	720[illegible]
Select Light 1 B On	[illegible]	7204
Select Light 1 B Off	720[illegible]	7205
Select Light 1C-On	7210	7210
Select Light 1C-Off	7211	7211
Select Light 1D-On	7220	7220
Select Light 1D-Off	7221	7221
Select Light 1E-On	7240	7240
Select Light 1E-Off	7241	7241
Select Light 2A-On	7[illegible]02	7[illegible]02
Select Light 2A-Off	7[illegible]03	7[illegible]03
↓	↓	↓
Select Light 6E-Off	7741	7741

Keyboard 2-Light Designation--

Figure 7-7
Select Function Codes for Light Sequence

8. System Implementation and Conclusions

The preceeding chapters described the design details of the functions to be performed by the DD-65. The complete block diagrams for the DD-56 are shown in Figures 8-1 and 8-2. The physical design of the unit requires over 1,500 logic circuit cards. In addition to these components, a number of power supplies and the deflection circuits for the display tubes are required. This large number of components, a number of power supplies and the deflection circuits for the display tubes are required. This large number of components prohibited a single cabinet design for the equipment. The digital logic has been placed in a separate cabinet which also contains all the low voltage power supplies for the digital circuits and the data line terminations from the computers. The operator's console contains the manual inputs and the display tubes as well as the high voltage power supplies to control the display tubes. Also incorporated in the operator's console are the digital to analog conversion circuits and the radar video circuits.

The entire system block diagram is shown in Figure 8-3. The pulse amplifier, video amplifier, and video quantizer are designed for implementation on the same size printed circuit cards as are used in the digital circuits. This allows these circuits to be contained within the logic cabinet of the DD-65. The final configuration of the DD-65 led to the proposed placement of the equipment in the Digital Automation and Control Laboratory as shown in Figure 8-4. The installation should be completed by August 1962.

The system, as designed, allows a great deal of programming flexibility and, therefore, a similar flexibility in respect to use of the operator's console. No attempt will be made here to flow-chart or dictate the type of system programs to be used with the DD-65, but a broad overview of possible functions will be undertaken. The discussion will be slanted toward specification of labels for the various overlays and operator keys. See Figure 8-5 for a diagram of entire operator's console.

The basic set of eight overlays could be specified as follows:

a. Air surveilence and flight following

b. Air intercept and control

c. Program composition and de-bugging

d. Servomechanism design

e. Network synthesis

f. Library information retrieval and update

g. Linear programming package

h. Statistical analysis package

Additional sets of overlays could be used by merely changing the system library tape in the computing center. These overlays have twenty unique function keys available for use which have the labels associated with them changed each time the overlay is changed. These labels and, hence, the programmed functions should include only those functions which are not common to all usage overlays.

The individual labels and associated programs can be determined only by actually outlining each overlay program in considerable detail. A few possible functions that could be associated with the

"programming" overlay are the selection of the various languages to be used for coding. These language select keys would set up a format subroutine for accepting "symbol keyboard" information. For instance, the "tab" key would produce character spacing which would be compatible with the format normally used to input the language to the computer. Further "step process" keys could be labeled for the storing of a completed program on a magnetic tape library or for a "trace" mode of running for de-bugging purposes.

Those functions which are common to all overlays are to be controlled by the ten function keys which are associated with light feedbacks, but whose labels are not changed with the overlay change. The possible set of functions to be programmed with these keys are:

a. Tube "0" display

b. Tube "1" display

c. "Display" track ball

d. "Hook" track ball

e. "Drop" track ball

f. Enter data

g. Delete data

h. Start process

i. Stop process

j. Load library

These functions are tentative, but the set of functions described are common to all the proposed overlays, and the subroutines involved should not take many cells of the memory to implement. The track ball sequence, as proposed, will entail calling for the dis-

play of the track ball on a particular tube, and then the operator can move the displayed "TB" symbol to the desired position by movement of the track ball. The "hook" track ball can then be executed which can have various meanings depending on the usage overlay. Possible uses of "hook" would be to insert a point or symbol at the designated spot on the display or the process could be reversed, and information concerning the point which is designated by the "TB" symbol could be displayed. The "drop" track ball could be executed after either a "display" or "hook". This function command could mean to delete a symbol or point from the display or drop the "TB" symbol and/or the amplifying information called up by the hook. The "Load", "Start", and "Stop" functions are proposed to be associated with the handling of display data within the computer. For instance, to enter a line of data could mean to place it into permanent storage location for processing after the temporary (for display purposes) information has been verified as correct.

The remaining four function keys are to be marked with direction arrows and are proposed to be used to move an editing symbol over the chosen display tube for purposes of locating the position for typing in or erasing information.

The actual operation of a system as proposed would require an overlay to be inserted and a library load executed. The computer, when ready to commence, would light the "start" process light. The operator, upon depressing the "start" process button, causes the computer to drop the selected light and start through the executive program. Upon reaching various points in the programs where infor-

mation is needed from the operator, various lights or groups of lights are selected "on" by the computer. The function labels associated with the lights outline the required action or inputs to be initiated by the operator. In this manner of reply-request-display, the man can thread through the programs in close association with the computer until the operator chooses to stop the process by depressing the "stop" function key.

It is felt that the flexibility in usage of the command console and the speed and packing density of the display information will provide an experimental device for man-computer systems which will not rapidly become obsolescent.

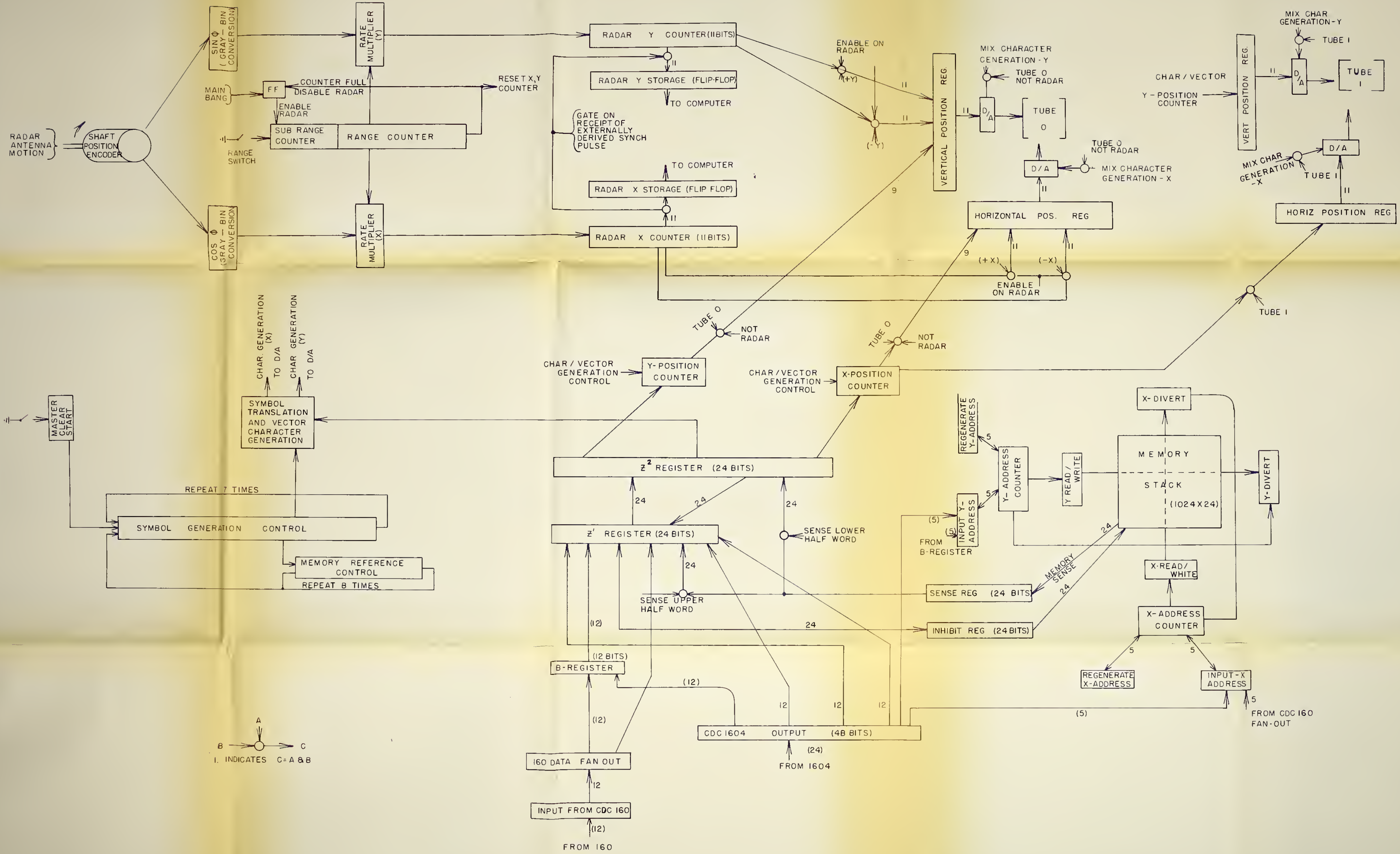


FIG. B-1 BLOCK DIAGRAM OF THE SYMBOL & RADAR GENERATORS & THE MEMORY

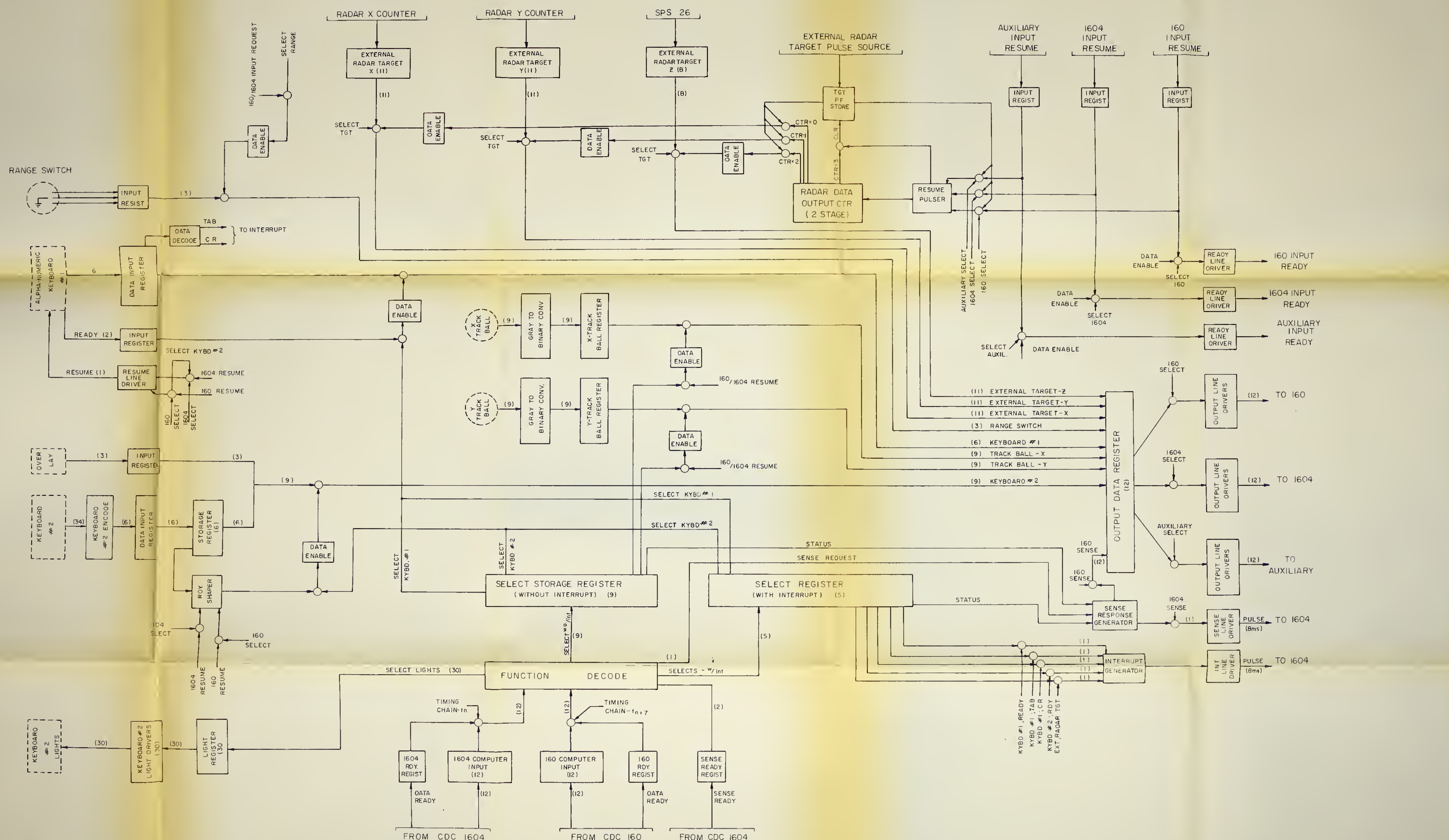
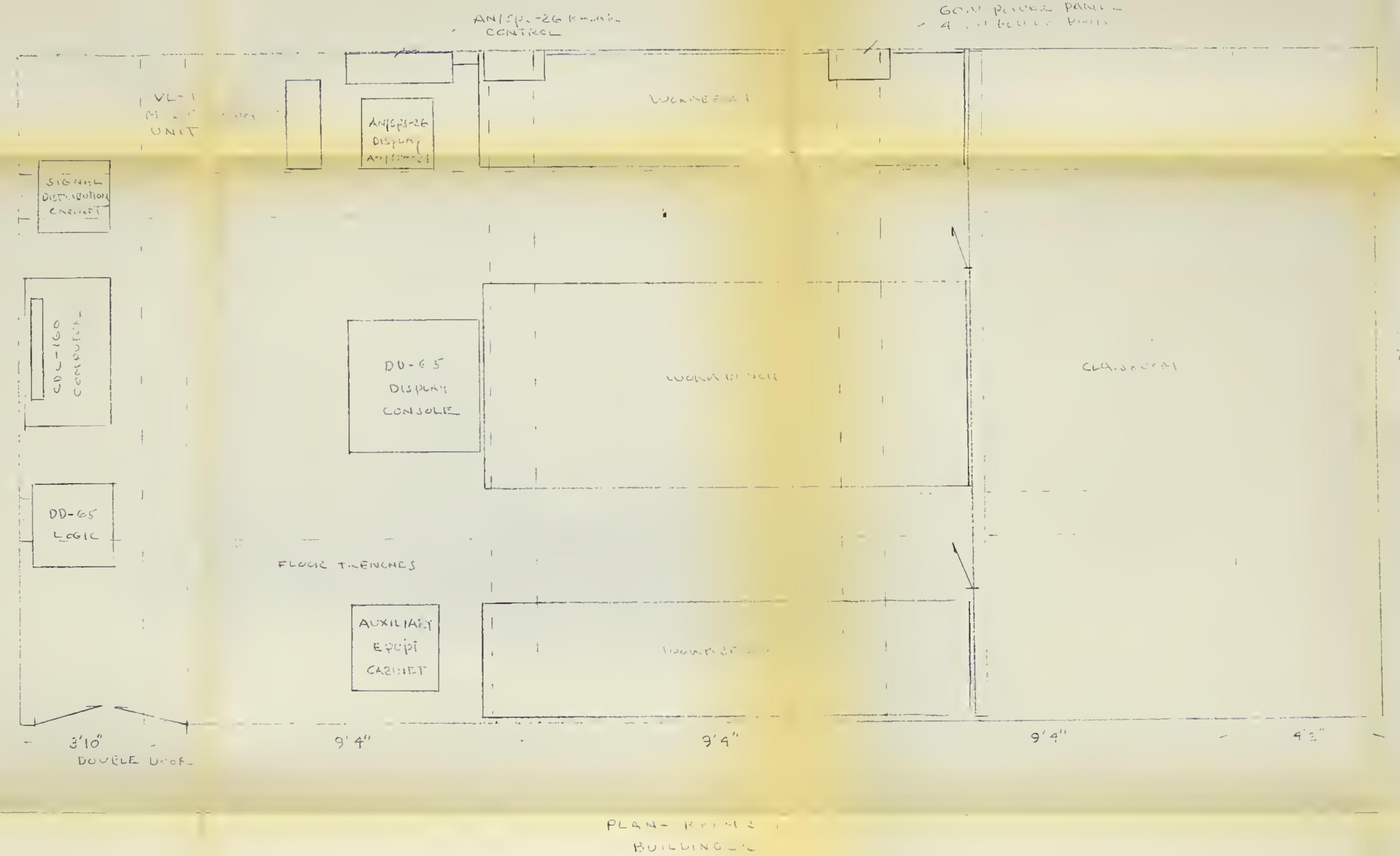


FIG. 8-2 BLOCK DIAGRAM OF THE CONTROL CIRCUITS

FIG. 8-3 BLOCK DIAGRAM OF THE ENTIRE SYSTEM
PAGE 81

DD 65	
LOGIC CABINET :	68" HIGH
	41" DEEP
	37 3/4" WIDE
OPERATOR'S CONSOLE :	49" HIGH
	51" DEEP
	60" WIDE



REVISION	DATE	APPD	DESCRIPTION	BY

DES.
DWN.
CHK.
PROJ. ENG.
BRANCH HD.
DIVISION HD.
SCALE: NO SCALE
SHEET 2 OF
DATE

Industrial Manager, USN, 12th Naval District
ELECTRONICS DEPARTMENT

U S NAVAL POSTGRADUATE
DIGITAL CONTROL
FLOOR PLAN &
EQUIPMENT LAYOUT

APPROVED
ELECTRONICS ASST.
FOR INDMAN 12ND

SATISFACTORY TO
USN
FOR
DATE

INDMAN 12ND SKETCH NO.

FIG 8-4 PROPOSED EQUIPMENT LAYOUT FOR THE DIGITAL CONTROL & AUTOMATION LABORATORY

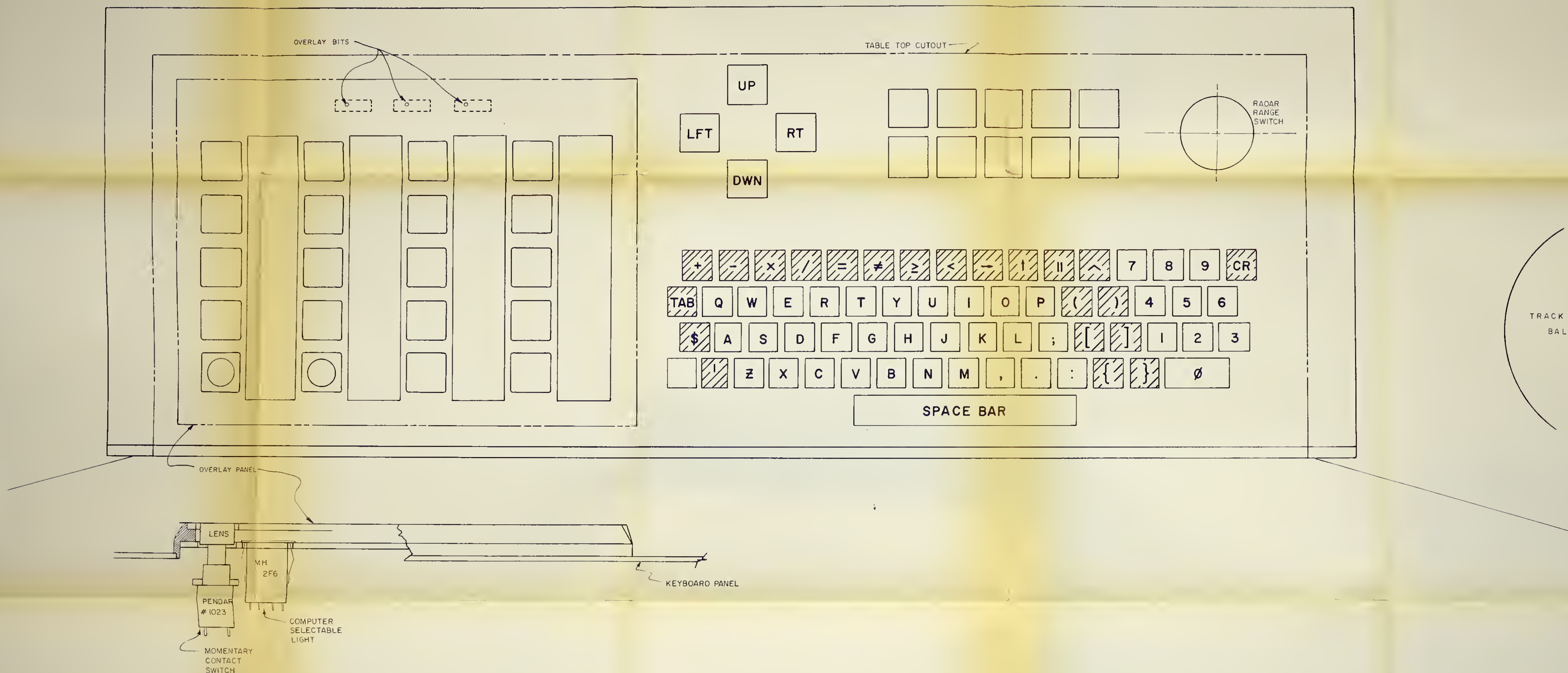


FIG. 8-5 LAYOUT OF THE OPERATORS CONSOLE

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APPENDIX I

DESIGN MECHANIZATION SYSTEM

Description, use and coding of a Control Data Corporation 1604 program for mechanizing portions of the design of digital equipments using Control Data Corporation type logic cards and format.

This appendix is written in standard "Co-op"[1] program description form.

Examples of sample outputs and inputs are shown in Figures 4-4 through 4-7 of this thesis.

[1] "Co-op" is the Control Data Corporation 1604 user group organization.

A. IDENTIFICATION

Title: Card Assignment and Wiring List Assembler for Control Data Corporation Input File of Equations

Category: Logical Design Aid

Programmer: C. G. Lawson

Date: 30 January 1962

B. PURPOSE

This routine is a composite of two separate functions:

1. It completes a file of equations and assigns card types to each equation for a given set of input equations.

2. It also computes and lists a wiring table if chassis locations for each section are designated.

In order to accomplish the first function, a magnetic tape containing punched card images of the input equations are processed by compiling an input table for the entire set of equations. This table is then searched to make up a list of outputs for each card. The number of inputs and outputs are then counted and logic cards are assigned, based upon the constraints of the family of cards. Certain special card types may be designated in the equation statements by special symbols. The number of cards required are counted during this process, and any erroneous equations are noted. The output at this point is a magnetic tape having the original input equations, each followed by a line containing the card type and a list of output destinations. Also, for any erroneous equations a star is placed in the left column adjacent to the equations. Following the equation file on the tape is a list of the card types

and the total number of each required for the design.

The second part of the program adds to the output tape a wiring tabulation of the intercard wires. In order to make up "wire tabs" the location of each section must be designated. This is done by adding the location information to the punched card for each equation. The program is then run with jump key one set and with an input of a magnetic tape containing the punched card images of the equations and locations. When there is a choice of wiring between points, the program compares lengths and assigns the shortest interconnection possible. The output is now a magnetic tape which contains all of the output lists.

The purpose for separating the program outputs is due to consideration of design proceedures. In most cases the file of equations are written from logic diagrams which do not necessarily show all the output wires. The clarity of the diagrams is improved if fewer interconnection lines need be shown. Therefore, the type card cannot always be assigned before finding how many outputs are needed. Also, if the total number of outputs required are more than the legal possible number of outputs, paralleling of signals is necessary. These considerations dictate that the completion of a design be done in two parts. The first part is to find out the card types necessary and to point out any errors in the equations. The location for the sections may now be assigned based upon the knowledge of card types and, also, any corrections may be entered into the input equations by changing the erroneous punched cards. The new inputs will now allow the output of all the desired lists

for writing the comsubi.

b. Usage

1. Calling Sequence:

a. On bioctal tape at present time

b. Start location =5000

c. Successful completion leaves 1000 in U

2. Arguments: none

3. Space required: 1000 cells

4. Temporary storage requirements: 1500 + 18X (number of input equations)

5. Alarms: none

6. Error returns: none

7. Error stops: 5455 in U if output criteria not satisfied (may be restarted if desired as errors will be indicated on printout)

105 in U if inconsistancies in designation are encountered

8. Input and output tape mountings:

a. Input:

(1) Source tape: on 5 202

b. Output:

(1) Output tape A: on 4 105

9. Input and output formats:

a. Input: 1000 80 character card image of input equations. Input equations written in standard ... format (see references).

(1) Input for card assignment only (jump key 1 not set):

(a) Each term must consist of four alphanumeric characters.

(b) The function must be the first term of the equation.

(c) The only restrictions on spacing or locations on the card is that columns 75 through 80 be set aside for insertion of location when assigned.

(d) The following characters are defined as operators when used in a logical equation:

space + - * / ( ) _ , ꜛ .

(e) All entries following . / ꜛ * , ( ) are treated as remarks.

(f) A maximum of 16 input terms may be used in an equation

(g) A maximum of 100 output uses will be compiled for a function

(h) When inserted anywhere following the equation, these symbols define unique types of cards:

. or space only	inverters (series 10 and 20)
*	flip-flops (series 30) (one flip-flop per card)
ꜛ	input cards (61) (three inverters per card)
/	output cards (62) (three inverters per card)
,	clock cards (01) (two oscillators per card)

(single inverter (S35) (three inverters per card)

) diode fanout (S04) (three sets of three diodes each per card)

(i) If flip-flops (series 30) designated, the pair input equations should be adjacent, and the implicit input should be the first OR term.

(2) Input for complete program (jump key one set): In addition to (a) through (i) above, the location must be typed into columns 77 through 80 and should have the following format:

Input card column	77	78 and 79	80
Meaning	ROW	COLUMN	SECTION
Allowable contents	A thru R	01 thru 99	A for 10 series A or C for 20 and 30 series or clock S04 A, B or C for 60 series or S36

Columns 73 through 76 can be used to identify chassis.

b. Outputs: 120 character line image in program control format for listing on output tape A.

(1) Outputs for card assignment only (jump key 1 not set):

(a) comments lines where applicable

(b) input equation lines as read in

(c) output lines with card type followed by list of output locations (following each input line)

(d) tabulation of the number of cards necessary to

implement the design.

(e) If any errors occur, such as too many inputs or outputs, no assignment is made and an error symbol is placed in the output line (along with an error stop).

(2) Outputs for complete program (jump key one set):

(a) as above

(b) input equation lines minus the location information

(c) output lines with location and card type followed by list of output locations (following each input line)

(d) as above

(e) tabulation of wiring data containing the following:

(e-1) origin and destination by row, column and pin number, if an internal card or by designation if external input

(e-2) designations of the above origin and destinations

(e-3) wire length in inches

(e-4) separation of ANDed groups by symbol * in left column

10. Selective jump and stop settings:

a. First run: none - to obtain card types

b. Second run: Jump key one set - to allow processing of

location information

11. Timing: depends on number of input equations

12. Accuracy: not applicable

13. Cautions to user: No tape errors are checked in the routine.

14. Equipment configuration: 1604 with two 1607 units; 1607 tape mountings to include a "scratch tape" on Ch4 TU4

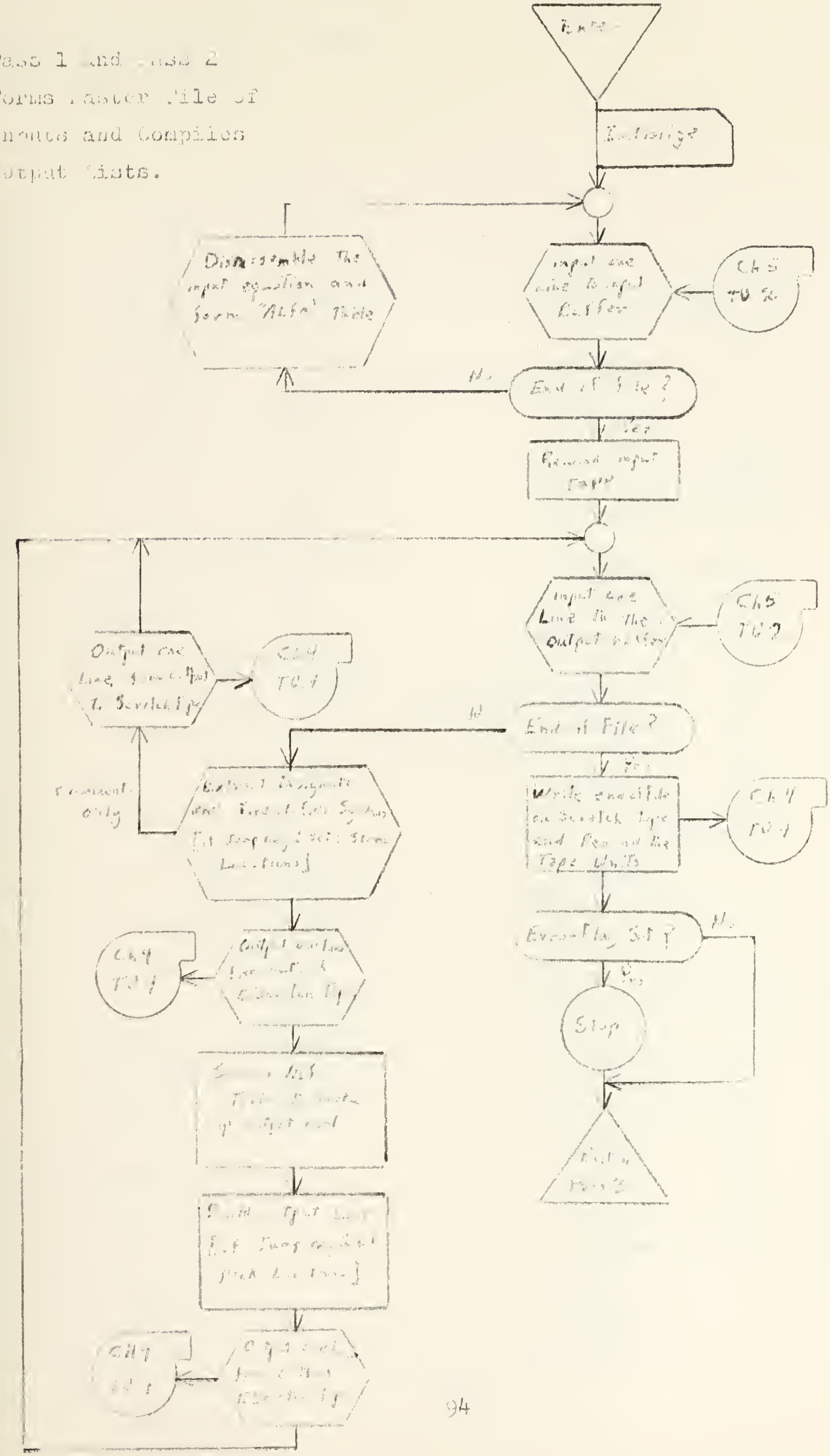
15. References:

   a. 1604 Computer Instruction Book, Vol. 1, Description and Operations, Control Data Corporation

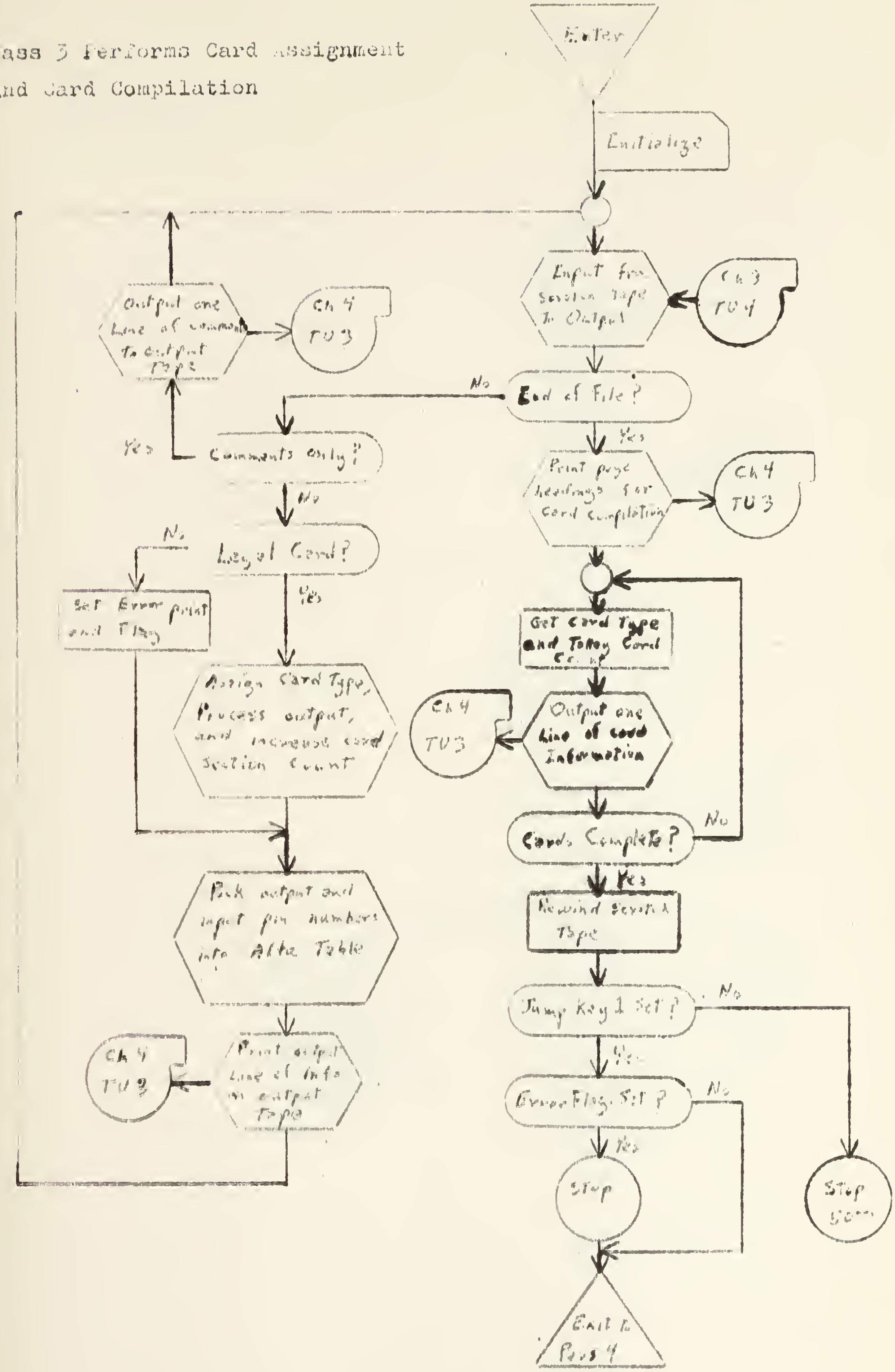
   b. 1604 Computer Instruction Book, Vol. 2, Principals of Operations, Control Data Corporation

   c. H. Loberman and A. Weinberger, Formal Procedures for Connecting Terminals with a Minimum Total Wire Length, J. Assoc. Computing Machinery, Vol. 4, no. 4, pp. 428-437, October, 1957

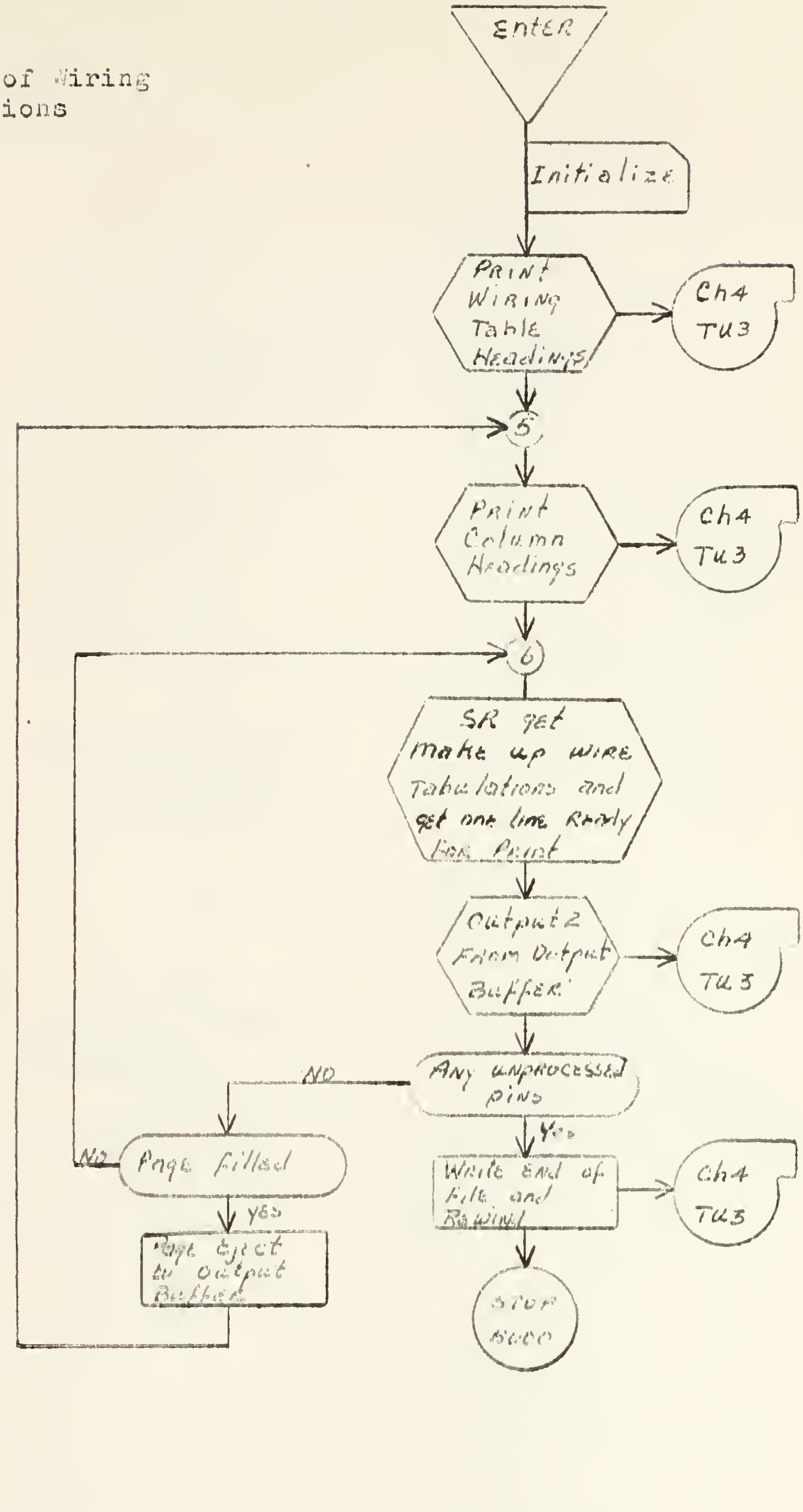
Pass 1 and Pass 2
Forms Master File of
Inputs and Compiles
Output Lists.



Pass 3 Performs Card Assignment and Card Compilation



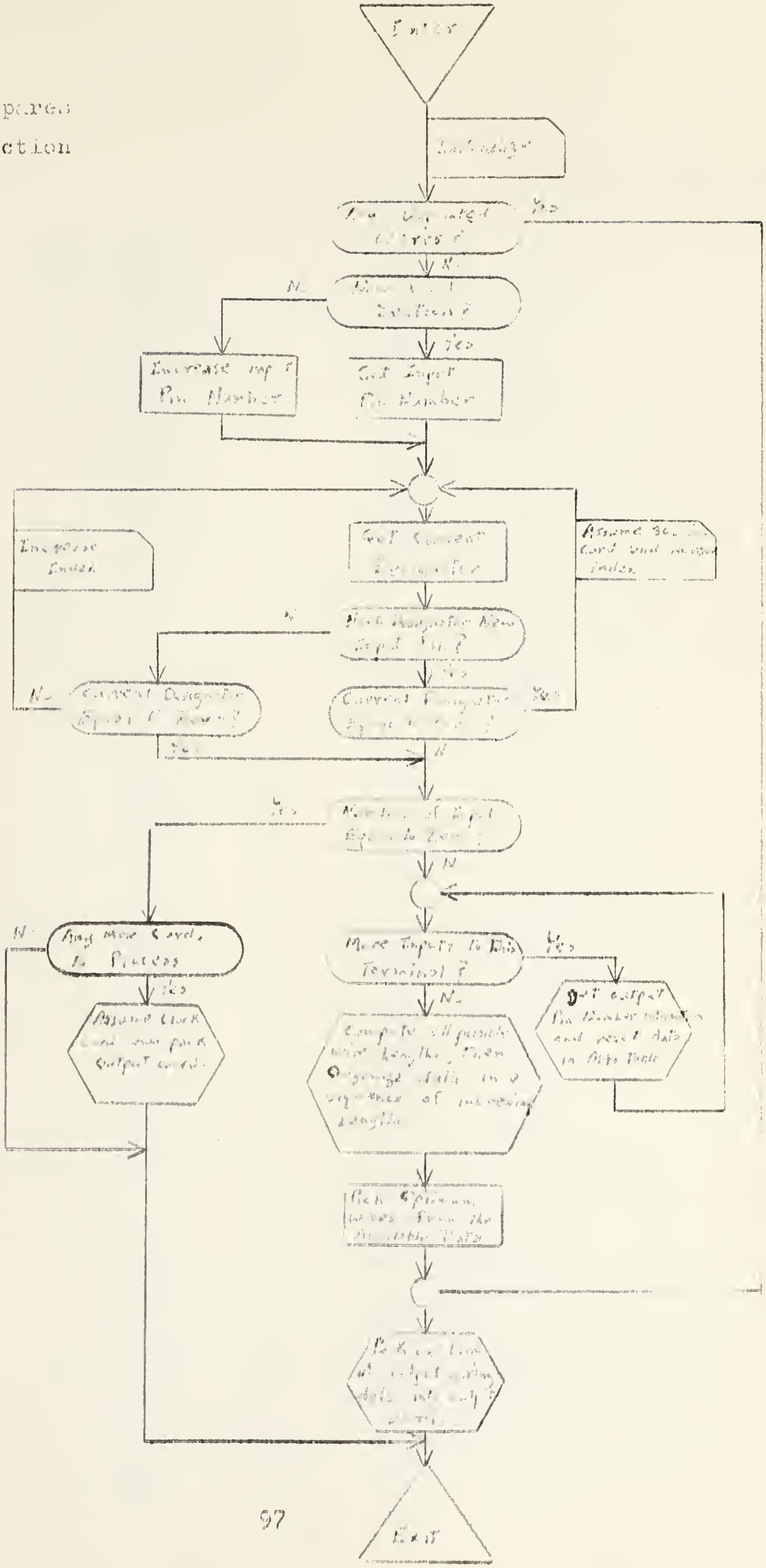
Pass 4
Makeup of Wiring
Tabulations



Subroutine [illegible]T

Chooses and Prepares

Best Wire Collection



```
                                          ORG      5000
                                          REM      PART ONE OF THE LOCI
                                          REM      SUBROUTINE WHICH COL
                                          REM      LOGICAL EQUATIONS AN
                                          REM      ON THE LINE IMMEDIAT
05000      50 1 00000                     ENI    1 0
           10 0 00000                     ENA    0 0
05001      20 1 10000                     STA    1 ADBUF
           50 0 00000                     ENI    0 0
05002      54 1 67700                     ISK    1 67700
           75 0 05001                     SLJ    0 /-1
05003      20 0 05253                     STA    0 FLAG
           20 0 05310                     STA    0 PAGE
05004      20 0 06067                     STA    0 WAIT
           20 0 06064                     STA    0 COUNT
05005      50 0 00000        INPUT        ENI    0 0
           74 7 52000                     EXF    7 52000
05006      10 0 05267                     ENA    0 INBUF+10D
           61 0 00005                     SAL    0 5
05007      74 0 52022                     EXF    0 52022
           74 7 52000                     EXF    7 52000
05010      74 5 05255                     EXF    5 INBUF
           74 7 52000                     EXF    7 52000
05011      74 7 52006                     EXF    7 52006
           75 0 05044                     SLJ    0 DISASS
05012      74 5 05267                     EXF    5 INBUF+10D
           50 0 00000                     ENI    0 0
05013      74 0 52005                     EXF    0 52005
           57 1 07226                     SIL    1 GOFER
05014      12 0 07226                     LDA    0 GOFER
           20 0 05242                     STA    0 TEMP+1
05015      75 4 05202                     SLJ    4 FILL
           50 0 00000                     ENI    0 0
05016      50 0 00000        ELEV         ENI    0 0
           74 7 52000                     EXF    7 52000
05017      10 0 05302                     ENA    0 OUTBUF+11D
           61 0 00005                     SAL    0 5
05020      74 0 52022                     EXF    0 52022
           74 7 52000                     EXF    7 52000
05021      74 5 05270                     EXF    5 OUTBUF+1
           74 7 52000                     EXF    7 52000
05022      74 7 52006                     EXF    7 52006
           75 0 05037                     SLJ    0 TWELVE
05023      74 5 05302                     EXF    5 OUTBUF+11D
           74 7 42000                     EXF    7 42000
05024      74 0 42042                     EXF    0 42042
           74 0 42003                     EXF    0 42003
05025      74 7 42000                     EXF    7 42000
           74 0 42005                     EXF    0 42005
05026      74 0 52005                     EXF    0 52005
           12 0 05253                     LDA    0 FLAG
05027      22 0 05456                     AJP    0 PASS3
           10 0 00000                     ENA    0 0
05030      20 0 05253                     STA    0 FLAG
           76 0 05456                     SLS    0 PASS3
05031      75 0 00000        OUTPUT       SLJ    0 0
           74 7 42000                     EXF    7 42000
05032      20 0 05246                     STA    0 TEMP+5
           72 0 05310                     RAO    0 PAGE
05033      10 0 05306                     ENA    0 OUTBUF+15D
           61 0 00004                     SAL    0 4
05034      74 0 42042                     EXF    0 42042
           74 7 42000                     EXF    7 42000
05035      74 4 05267                     EXF    4 OUTBUF
           74 7 42000                     EXF    7 42000
05036      12 0 05246                     LDA    0 TEMP+5
           75 0 05031                     SLJ    0 OUTPUT
05037      75 4 05077       TWELVE        SLJ    4 EXTRACT
           50 0 00000                     ENI    0 0
05040      75 4 05031                     SLJ    4 OUTPUT
           50 0 00000                     ENI    0 0
```

```
05041   12 0 05252              LDA  0 SPACE
        20 0 05267              STA  0 OUTBUF
05042   20 0 05305              STA  0 OUTBUF+14D
        12 0 05241              LDA  0 TEMP
05043   50 0 00000              ENI  0 0
        75 0 05125              SLJ  0 SEARCH
05044   50 2 00000   DISASS     ENI  2 0
        50 3 00000              ENI  3 0
05045   50 4 00000              ENI  4 0
        50 5 00000              ENI  5 0
05046   50 6 00000              ENI  6 0
        10 0 00000              ENA  0 0
05047   16 2 05255   ONE        LDQ  2 INBUF
        50 0 00000              ENI  0 0
05050   05 0 00006   TWO        ALS  0 6
        20 0 05241              STA  0 TEMP
05051   10 0 00000              ENA  0 0
        07 0 00006              LLS  0 6
05052   50 6 00013              ENI  6 11D
        50 0 00000              ENI  0 0
05053   64 6 05206              EQS  6 LIST
        75 0 05063              SLJ  0 THREE
05054   10 6 00000              ENA  6 0
        22 1 05056              AJP  1 /+2
05055   10 5 00000              ENA  5 0
        22 0 05072              AJP  0 FIVE+2
05056   10 6 00000              ENA  6 0
        15 0 05254              SUB  0 UNITS
05057   22 3 05071              AJP  3 FIVE+1
        51 6 77770              INI  6 -7
05060   55 6 05061              IJP  6 /+1
        75 0 05075              SLJ  0 OR
05061   55 6 05062              IJP  6 /+1
        75 0 05075              SLJ  0 OR
05062   10 0 00000              ENA  0 0
        75 0 05067              SLJ  0 FOUR
05063   70 0 05241   THREE      RAD  0 TEMP
        50 0 00000              ENI  0 0
05064   54 3 00003              ISK  3 3
        75 0 05067              SLJ  0 FOUR
05065   70 1 16000              RAD  1 ALFA
        51 5 00001              INI  5 1
05066   51 1 00001              INI  1 1
        10 0 00000              ENA  0 0
05067   54 4 00007   FOUR       ISK  4 7
        75 0 05050              SLJ  0 TWO
05070   54 2 00010   FIVE       ISK  2 10
        75 0 05047              SLJ  0 ONE
05071   54 5 00022              ISK  5 22
        75 0 05073              SLJ  0 /+2
05072   75 0 05005              SLJ  0 INPUT
        50 0 00000              ENI  0 0
05073   10 0 00000              ENA  0 0
        20 1 16000              STA  1 ALFA
05074   51 1 00001              INI  1 1
        75 0 05071              SLJ  0 /-3
05075   12 0 05455   OR         LDA  0 BIT48
        20 1 16000              STA  1 ALFA
05076   10 0 00000              ENA  0 0
        75 0 05067              SLJ  0 FOUR
05077   75 0 00000   EXTRACT    SLJ  0 0
        10 0 00000              ENA  0 0
05100   50 5 00000              ENI  5 0
        16 0 05270              LDQ  0 OUTBUF+1
05101   05 0 00006              ALS  0 6
        20 0 05241              STA  0 TEMP
05102   10 0 00000              ENA  0 0
        50 0 00000              ENI  0 0
05103   07 0 00006              LLS  0 6
        50 6 00013              ENI  6 11D
05104   64 6 05206              EQS  6 LIST
        75 0 05107              SLJ  0 /+3
05105   10 6 00000              ENA  6 0
```

```
         22 0 05172             AJP  0 TENA-1
05106    75 0 05102             SLJ  0 /-4
         50 0 00000             ENI  0 0
05107    70 0 05241             RAD  0 TEMP
         50 0 00000             ENI  0 0
05110    54 5 00003             ISK  5 3
         75 0 05101             SLJ  0 /-7
05111    50 3 00000             ENI  3 0
         50 2 00000             ENI  2 0
05112    75 5 05773             SLJ  5 MAKEX
         50 0 00000             ENI  0 0
05113    16 2 05270             LDQ  2 OUTBUF+1
         50 0 00000             ENI  0 0
05114    10 0 00000             ENA  0 0
         50 0 00000             ENI  0 0
05115    07 0 00006             LLS  0 6
         50 6 00007             ENI  6 7
05116    64 6 05206             EQS  6 LIST
         75 0 05120             SLJ  0 /+2
05117    75 0 05122             SLJ  0 /+3
         50 0 00000             ENI  0 0
05120    54 3 00007             ISK  3 7
         75 0 05114             SLJ  0 /-4
05121    54 2 00010             ISK  2 8D
         75 0 05113             SLJ  0 /-6
05122    12 6 05232             LDA  6 CARD21
         20 0 05305             STA  0 OUTBUF+140D
05123    12 6 05221             LDA  6 CHECK
         61 0 05247             SAL  0 EIGHT
05124    75 0 05077             SLJ  0 EXTRACT
         50 0 00000             ENI  0 0
05125    53 1 05242    SEARCH   LIL  1 TEMP+1
         50 3 00000             ENI  3 0
05126    16 0 06113    SIX      LDQ  0 LCMASK
         50 0 00000             ENI  0 0
05127    66 1 16000             MEQ  1 ALFA
         75 0 05141             SLJ  0 BUILD
05130    57 1 07226             SIL  1 GOFER
         12 0 07226             LDA  0 GOFER
05131    04 0 00000             ENQ  0 0
         22 0 05141             AJP  0 BUILD
05132    25 0 05230             DVI  0 INCRM
         23 0 05140             QJP  0 SEVEN
05133    57 1 07226             SIL  1 GOFER
         12 0 07226             LDA  0 GOFER
05134    21 0 05231             STQ  0 DECRM
         15 0 05231             SUB  0 DECRM
05135    20 0 05231             STA  0 DECRM
         53 2 05231             LIL  2 DECRM
05136    16 0 06113             LDQ  0 LCMASK
         44 2 16000             LPL  2 ALFA
05137    20 3 05311             STA  3 BETA
         51 3 00001             INI  3 1
05140    12 0 05241    SEVEN    LDA  0 TEMP
         75 0 05126             SLJ  0 SIX
05141    75 4 05202    BUILD    SLJ  4 FILL
         50 0 00000             ENI  0 0
05142    75 1 05143             SLJ  1 /+1
         75 0 05144             SLJ  0 /+2
05143    12 0 06066             LDA  0 HOLD
         20 0 05270             STA  0 OUTBUF+1
05144    55 3 05145             IJP  3 /+1
         75 0 05167             SLJ  0 PRNONE
05145    10 3 00000             ENA  3 0
         15 0 05247             SUB  0 EIGHT
05146    22 3 05150             AJP  3 /+2
         12 0 05251             LDA  0 STAR
05147    20 0 05267             STA  0 OUTBUF
         72 0 05253             RAO  0 FLAG
05150    75 0 05152             SLJ  0 /+2
         50 0 00000             ENI  0 0
05151    75 4 05202             SLJ  4 FILL
         50 0 00000             ENI  0 0
```

```
05152    50 4 00002                ENI   4  2
         10 3 00000                ENA   3  0
05153    60 0 05162                SAU   0  NINE+5
         60 0 05171                SAU   0  TEN
05154    50 3 00000                ENI   3  0
         50 0 00000                ENI   0  0
05155    16 0 05250     NINE       LDQ   0  COMMA
         12 3 05311                LDA   3  BETA
05156    07 0 00030                LLS   0  24D
         50 0 00000                ENI   0  0
05157    20 4 05270                STA   4  OUTBUF+1
         50 0 00000                ENI   0  0
05160    54 4 00015                ISK   4  13D
         75 0 05171                SLJ   0  TEN
05161    75 4 05031                SLJ   4  OUTPUT
         50 0 00000                ENI   0  0
05162    54 3 00000                ISK   3  0
         75 0 05164                SLJ   0  /+2
05163    75 0 05173                SLJ   0  TENA
         50 0 00000                ENI   0  0
05164    75 4 05202                SLJ   4  FILL
         50 0 00000                ENI   0  0
05165    12 0 05232                LDA   0  CARD21
         20 0 05270                STA   0  OUTBUF+1
05166    50 4 00002                ENI   4  2
         75 0 05155                SLJ   0  NINE
05167    12 0 05306     PRNONE     LDA   0  NONE
         20 0 05272                STA   0  OUTBUF+3
05170    75 0 05172                SLJ   0  TEN+1
         50 0 00000                ENI   0  0
05171    54 3 00000     TEN        ISK   3  0
         75 0 05155                SLJ   0  NINE
05172    75 4 05031                SLJ   4  OUTPUT
         50 0 00000                ENI   0  0
05173    75 4 05202     TENA       SLJ   4  FILL
         50 0 00000                ENI   0  0
05174    75 4 05031                SLJ   4  OUTPUT
         50 0 00000                ENI   0  0
05175    20 0 05246                STA   0  TEMP+5
         10 0 00110                ENA   0  72D
05176    65 0 05310                THS   0  PAGE
         75 0 05016                SLJ   0  ELEV
05177    10 0 00000                ENA   0  0
         20 0 05310                STA   0  PAGE
05200    12 0 05307                LDA   0  EJECT
         20 0 05267                STA   0  OUTBUF
05201    12 0 05246                LDA   0  TEMP+5
         75 0 05016                SLJ   0  ELEV
05202    75 0 00000     FILL       SLJ   0  0
         50 5 00000                ENI   5  0
05203    12 0 05252                LDA   0  SPACE
         20 5 05267                STA   5  OUTBUF
05204    54 5 00016                ISK   5  14D
         75 0 05203                SLJ   0  /-1
05205    75 0 05202                SLJ   0  FILL
         50 0 00000                ENI   0  0
05206    00 0 00000     LIST       OCT      73
         00 0 00073
05207    00 0 00000                OCT      54
         00 0 00054
05210    00 0 00000                OCT      53
         00 0 00053
05211    00 0 00000                OCT      21
         00 0 00021
05212    00 0 00000                OCT      33
         00 0 00033
05213    00 0 00000                OCT      34
         00 0 00034
05214    00 0 00000                OCT      74
         00 0 00074
05215    00 0 00000                OCT      60
         00 0 00060
05216    00 0 00000                OCT      13
```

```
      00 0 00013 .
05217 00 0 00000                 OCT     14
      00 0 00014
05220 00 0 00000                 OCT     20
      00 0 00020
05221 00 0 00000     CHECK       OCT     10
      00 0 00010
05222 00 0 00000                 OCT     5
      00 0 00005
05223 00 0 00000                 OCT     2
      00 0 00002
05224 00 0 00000                 OCT     1
      00 0 00001
05225 00 0 00000                 OCT     5
      00 0 00005
05226 00 0 00000                 OCT     1
      00 0 00001
05227 00 0 00000                 OCT     3
      00 0 00003
05230 00 0 00000     INCRM       OCT     22
      00 0 00022
05231 00 0 00000     DECRM       BSS     1
      00 0 00000
05232 20 2 02020     CARD21      BCD     /         .
      20 2 02073
05233 20 2 02020     CARD31      BCD     /         *
      20 2 02054
05234 20 2 02020     CARD61      BCD     /         $
      20 2 02053
05235 20 2 02020     CARD62      BCD     /         /
      20 2 02021
05236 20 2 02020     CARD01      BCD     /         ,
      20 2 02033
05237 20 2 02020     CARDS36     BCD     /         (
      20 2 02054
05240 20 2 02020     CARDS04     BCD     /         )
      20 2 02074
05241 00 0 00000     TEMP        BSS     6
      00 0 00000
05247 00 0 00000     EIGHT       OCT     10
      00 0 00010
05250 33 2 02020     COMMA       BCD     /,
      20 2 02020
05251 20 2 02020     STAR        BCD     /       *
      20 5 42020
05252 20 2 02020     SPACE       BCD     /
      20 2 02020
05253 00 0 00000     FLAG        BSS     1
      00 0 00000
05254 00 0 00000     UNITS       OCT     7
      00 0 00007
05255 00 0 00000     INBUF       BSS     10D
      00 0 00000
05267 00 0 00000     OUTBUF      BSS     15D
      00 0 00000
05306 45 4 64565     NONE        BCD     /NONE
      20 2 02020
05307 01 2 02020     EJECT       BCD     /1
      20 2 02020
05310 00 0 00000     PAGE        BSS     1
      00 0 00000
05311 00 0 00000     BETA        BSS     100D
      00 0 00000
05455 60 0 00000     BIT48       OCT     6000000000000000
      00 0 00000
                                 REM     CARD ASSIGNMENT ROUTINE
05456 50 1 00032     PASS3       ENI   1 26D
      10 0 00000                 ENA   0 0
05457 20 1 06027                 STA   1 ICOUNT
      55 1 05457                 IJP   1 /
05460 75 4 05700     PASS3A      SLJ   4 INPUT2
      50 0 00000                 ENI   0 0
05461 74 7 32006                 EXF   7 32006
```

```
        75 0 05552              SLJ  0 TEST
05462   74 3 05306              EXF  3 OUTBUF+150
        75 4 05202              SLJ  4 FILL
05463   12 0 06010              LDA  0 PAGEJ
        20 0 05267              STA  0 OUTBUF
05464   75 4 05705              SLJ  4 OUTPUT2
        50 0 00000              ENI  0 0
05465   75 4 05717              SLJ  4 CLRBUF
        50 0 00000              ENI  0 0
05466   10 0 06140              ENA  0 HEAD1
        60 0 05713              SAU  0 MSG+1
05467   12 0 06012              LDA  0 LNGTH1
        60 0 05714              SAU  0 MSG+2
05470   75 4 05712              SLJ  4 MSG
        50 0 00000              ENI  0 0
05471   75 4 05717              SLJ  4 CLRBUF
        50 0 00000              ENI  0 0
05472   10 0 06150              ENA  0 HEAD2
        60 0 05713              SAU  0 MSG+1
05473   12 0 06013              LDA  0 LNGTH2
        60 0 05714              SAU  0 MSG+2
05474   75 4 05712              SLJ  4 MSG
        50 0 00000              ENI  0 0
05475   75 4 05717              SLJ  4 CLRBUF
        50 0 00000              ENI  0 0
05476   10 0 06155              ENA  0 HEAD3
        60 0 05713              SAU  0 MSG+1
05477   12 0 06014              LDA  0 LNGTH3
        60 0 05714              SAU  0 MSG+2
05500   75 4 05712              SLJ  4 MSG
        50 0 00000              ENI  0 0
05501   50 5 00000              ENI  5 0
        75 4 05717              SLJ  4 CLRBUF
05502   12 0 05252              LDA  0 SPACE
        20 0 05274              STA  0 OUTBUF+5
05503   20 0 05275              STA  0 OUTBUF+6
        50 0 00000              ENI  0 0
05504   12 5 06116              LDA  5 CARD
        20 0 05271              STA  0 OUTBUF+2
05505   12 5 06027              LDA  5 ICOUNT
        75 4 05512              SLJ  4 OCTBCD
05506   54 5 00021              ISK  5 17D
        75 0 05502              SLJ  0 /-4
05507   74 0 32005              EXF  0 32005
        12 0 05253              LDA  0 FLAG
05510   75 1 05511              SLJ  1 /+1
        76 0 05000              SLS  0 5000
05511   22 0 06163              AJP  0 PASS4
        76 0 06163              SLS  0 PASS4
05512   75 0 00000      OCTBCD  SLJ  0 0
        50 6 00000              ENI  6 0
05513   65 0 06020              THS  0 RFR03
        51 6 00001              INI  6 1
05514   65 0 06017              THS  0 RFR02
        51 6 00001              INI  6 1
05515   65 0 06016              THS  0 RFR01
        51 6 00001              INI  6 1
05516   65 0 06015              THS  0 RFR00
        51 6 00001              INI  6 1
05517   55 6 05520              IJP  6 /+1
        75 0 05532              SLJ  0 FRACT
05520   16 6 06021              LDQ  6 MASK
        21 0 05243              STQ  0 TEMP+2
05521   04 0 00000              ENQ  0 0
        21 0 05241              STQ  0 TEMP
05522   04 0 00000              ENQ  0 0
        25 6 06015              DVI  6 RFR00
05523   22 1 05524              AJP  1 /+1
        12 0 06107              LDA  0 ZERO
05524   20 0 05244              STA  0 TEMP+3
        12 0 05241              LDA  0 TEMP
05525   05 0 00006              ALS  0 6
        14 0 05244              ADD  0 TEMP+3
```

```
05526     20 0 05241             STA   0 TEMP
          21 0 05244             STQ   0 TEMP+3
05527     12 0 05244             LDA   0 TEMP+3
          55 6 05522             IJP   6 /-5
05530     12 0 05241             LDA   0 TEMP
          14 0 05243             ADD   0 TEMP+2
05531     20 0 05274             STA   0 OUTBUF+5
          50 0 00000             ENI   0 0
05532     10 5 00000   FRACT     ENA   5 0
          15 0 06026             SUB   0 TRIP
05533     22 2 05542             AJP   2 THIRD
          10 5 00000             ENA   5 0
05534     15 0 06025             SUB   0 DCUB
          22 2 05547             AJP   2 HALF
05535     12 0 05274   ITEST     LDA   0 OUTBUF+5
          15 0 05252             SUB   0 SPACE
05536     22 1 05540             AJP   1 OUTLINE
          12 0 05306             LDA   0 NONE
05537     20 0 05274             STA   0 OUTBUF+5
          50 0 00000             ENI   0 0
05540     75 4 05705   OUTLINE   SLJ   4 OUTPUT2
          50 0 00000             ENI   0 0
05541     75 0 05512             SLJ   0 OCTBCD
          50 0 00000             ENI   0 0
05542     12 5 06040   THIRD     LDA   5 FCOUNT-9D
          22 0 05535             AJP   0 ITEST
05543     64 0 06015             EQS   0 RER00
          75 0 05545             SLJ   0 /+2
05544     12 0 06072             LDA   0 ATHIRD
          75 0 05546             SLJ   0 /+2
05545     12 0 06073             LDA   0 BTHIRD
          50 0 00000             ENI   0 0
05546     20 0 05275             STA   0 OUTBUF+6
          75 0 05540             SLJ   0 OUTLINE
05547     12 5 06040   HALF      LDA   5 FCOUNT-9D
          22 0 05535             AJP   0 ITEST
05550     12 0 06074             LDA   0 AHALF
          20 0 05275             STA   0 OUTBUF+6
05551     75 0 05540             SLJ   0 OUTLINE
          50 0 00000             ENI   0 0
05552     12 0 05305   TEST      LDA   0 OUTBUF+14D
          50 1 00000             ENI   1 0
05553     64 0 05252             EQS   0 SPACE
          75 0 05560             SLJ   0 TEST2
05554     75 0 05556             SLJ   0 /+2
          50 0 00000             ENI   0 0
05555     75 5 05734   TEST1     SLJ   5 OUTPIN
          50 0 00000             ENI   0 0
05556     75 4 05705             SLJ   4 OUTPUT2
          50 0 00000             ENI   0 0
05557     75 0 05460             SLJ   0 PASS3A
          50 0 00000             ENI   0 0
05560     64 0 05234   TEST2     EQS   0 CARD61
          75 0 05570             SLJ   0 NEXT1
05561     75 4 05705   IOCD      SLJ   4 OUTPUT2
          50 0 00000             ENI   0 0
05562     75 4 05700             SLJ   4 INPUT2
          50 0 00000             ENI   0 0
05563     12 1 06134             LDA   1 CARD+14D
          20 0 05271             STA   0 OUTBUF+2
05564     72 1 06056             RAO   1 FCOUNT+5
          15 0 06077             SUB   0 TRIO
05565     22 0 05566             AJP   0 /+1
          75 0 05555             SLJ   0 TEST1
05566     10 0 00000             ENA   0 0
          20 1 06056             STA   1 FCOUNT+5
05567     72 1 06045             RAO   1 ICOUNT+14D
          75 0 05555             SLJ   0 TEST1
05570     64 0 05235   NEXT1     EQS   0 CARD62
          75 0 05655             SLJ   0 NEXT2
05571     50 1 00001             ENI   1 1
          75 0 05561             SLJ   0 ICCD
05572     64 0 05233   TEST3     EQS   0 CARD31
```

```
             75 0 05616             SLJ  0 TEST4
05573        50 6 00012             ENI  6 10D
             75 4 05723             SLJ  4 ORCOUNT
05574        75 4 05705             SLJ  4 OUTPUT2
             50 0 00000             ENI  0 0
05575        75 4 05700             SLJ  4 INPUT2
             50 0 00000             ENI  0 0
05576        12 0 06063             LDA  0 ORCNT
             50 0 00000             ENI  0 0
05577        64 0 06100             EQS  0 DUO
             75 0 05612             SLJ  0 TRY2
05600        12 1 06124    FFCD     LDA  1 CARD+6
             20 0 05271             STA  0 OUTBUF+2
05601        10 0 00001             ENA  0 1
             20 0 06070             STA  0 FFFLG
05602        72 1 06035             RAO  1 ICCOUNT+6
             75 5 05734             SLJ  5 OUTPIN
05603        75 4 05705             SLJ  4 OUTPUT2
             50 0 00000             ENI  0 0
05604        75 4 05700             SLJ  4 INPUT2
             50 0 00000             ENI  0 0
05605        75 4 05705             SLJ  4 OUTPUT2
             50 0 00000             ENI  0 0
05606        75 4 05700             SLJ  4 INPUT2
             50 0 00000             ENI  0 0
05607        12 1 06124             LDA  1 CARD+6
             20 0 05271             STA  0 OUTBUF+2
05610        12 0 05455             LDA  0 BI148
             20 2 16001             STA  2 ALFA+1
05611        75 0 05555             SLJ  0 TEST1
             50 0 00000             ENI  0 0
05612        64 0 06077    TRY2     EQS  0 TRIO
             75 0 05614             SLJ  0 TRY3
05613        50 1 00001             ENI  1 1
             75 0 05600             SLJ  0 FFCD
05614        64 0 06076    TRY3     EQS  0 QUAD
             75 0 05665             SLJ  0 ERROR1
05615        50 1 00002             ENI  1 2
             75 0 05600             SLJ  0 FFCD
05616        64 0 05232    TEST4    EQS  0 CARD21
             75 0 05661             SLJ  0 TEST5
05617        50 6 00012             ENI  6 10D
             75 4 05723             SLJ  4 ORCOUNT
05620        75 4 05705             SLJ  4 OUTPUT2
             50 0 00000             ENI  0 0
05621        75 4 05700             SLJ  4 INPUT2
             50 0 00000             ENI  0 0
05622        75 4 05672             SLJ  4 OUTCOUNT
             50 0 00000             ENI  0 0
05623        12 0 06063             LDA  0 ORCNT
             50 0 00000             ENI  0 0
05624        64 0 06075             EQS  0 QUINT
             75 0 05632             SLJ  0 TRY6
05625        12 1 06101    UNCD     LDA  1 OUTEND
             50 0 00000             ENI  0 0
05626        65 0 06062             THS  0 OUTCNT
             75 0 05630             SLJ  0 /+2
05627        75 0 05670             SLJ  0 ERROR2
             50 0 00000             ENI  0 0
05630        12 1 06122             LDA  1 CARD+4
             20 0 05271             STA  0 OUTBUF+2
05631        72 1 06033             RAO  1 ICOUNT+4
             75 0 05555             SLJ  0 TEST1
05632        64 0 06102    TRY6     EQS  0 SEXT
             75 0 05634             SLJ  0 INV1
05633        50 1 00001             ENI  1 1
             75 0 05625             SLJ  0 UNCD
05634        64 0 06015    INV1     EQS  0 RER00
             75 0 05647             SLJ  0 INV2
05635        12 1 06075    INCD     LDA  1 QUINT
             50 0 00000             ENI  0 0
05636        65 0 06062             THS  0 OUTCNT
             75 0 05641             SLJ  0 SER20
```

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05637   12 1 06116             LDA  1 CARD
        20 0 05271             STA  0 OUTBUF+2
05640   72 1 06027             RAO  1 ICOUNT
        75 0 05555             SLJ  0 TEST1
05641   51 1 00011  SER20      INI  1 9D
        12 1 06116             LDA  1 CARD
05642   20 0 05271             STA  0 OUTBUF+2
        72 1 06040             RAO  1 ICOUNT+9D
05643   15 0 06100             SUB  0 DUC
        22 0 05645             AJP  0 /+2
05644   75 0 05555             SLJ  0 TEST1
        50 0 00000             ENI  0 0
05645   10 0 00000             ENA  0 0
        20 1 06040             STA  1 ICOUNT+9D
05646   72 1 06027             RAO  1 ICOUNT
        75 0 05555             SLJ  0 TEST1
05647   64 0 06100  INV2       EQS  0 DUC
        75 0 05651             SLJ  0 INV3
05650   50 1 00001             ENI  1 1
        75 0 05635             SLJ  0 INCD
05651   64 0 06077  INV3       EQS  0 TRIO
        75 0 05653             SLJ  0 INV4
05652   50 1 00002             ENI  1 2
        75 0 05635             SLJ  0 INCD
05653   64 0 06076  INV4       EQS  0 QUAD
        75 0 05671             SLJ  0 ERROR3
05654   50 1 00003             ENI  1 3
        75 0 05635             SLJ  0 INCD
05655   64 0 05237  NEXT2      EQS  0 CARDS36
        75 0 05657             SLJ  0 NEXT3
05656   50 1 00002             ENI  1 2
        75 0 05561             SLJ  0 ICCD
05657   64 0 05240  NEXT3      EQS  0 CARDS04
        75 0 05572             SLJ  0 TEST3
05660   50 1 00003             ENI  1 3
        75 0 05561             SLJ  0 ICCD
05661   64 0 05236  TEST5      EQS  0 CARD01
        75 0 05665             SLJ  0 ERROR1
05662   50 1 00004             ENI  1 4
        75 4 05705             SLJ  4 OUTPUT2
05663   75 4 05700             SLJ  4 INPUT2
        50 0 00000             ENI  0 0
05664   75 0 05641             SLJ  0 SER20
        50 0 00000             ENI  0 0
05665   12 0 06103  ERROR1     LDA  0 TAGE
        50 0 00000             ENI  0 0
05666   20 0 05271             STA  0 OUTBUF+2
        72 0 05253             RAO  0 FLAG
05667   75 0 05555             SLJ  0 TEST1
        50 0 00000             ENI  0 0
05670   12 0 06104  ERROR2     LDA  0 OUTE
        75 0 05666             SLJ  0 /-2
05671   12 0 06105  ERROR3     LDA  0 INE
        75 0 05666             SLJ  0 /-3
05672   75 0 00000  OUTCOUNT   SLJ  0 0
        50 6 00013             ENI  6 11D
05673   10 0 00000             ENA  0 0
        20 0 06062             STA  0 OUTCNT
05674   12 0 06110             LDA  0 CMASK
        16 0 06110             LDQ  0 CMASK
05675   46 6 05272             SBL  6 OUTBUF+3
        22 1 05677             AJP  1 /+2
05676   72 0 06062             RAO  0 OUTCNT
        50 0 00000             ENI  0 0
05677   55 6 05674             IJP  6 /-3
        75 0 05672             SLJ  0 OUTCOUNT
05700   75 0 00000  INPUT2     SLJ  0 0
        74 7 32000             EXF  7 32000
05701   10 0 05306             ENA  0 OUTBUF+15D
        61 0 00003             SAL  0 3
05702   74 0 32042             EXF  0 32042
        74 7 32000             EXF  7 32000
05703   74 3 05267             EXF  3 OUTBUF
```

```
            74 7 32000              EXF  7 32000
05704       75 0 05700              SLJ  0 INPUT2
            50 0 00000              ENI  0 0
05705       75 0 00000   OUTPUT2    SLJ  0 0
            74 7 42000              EXF  7 42000
05706       10 0 05306              ENA  0 OUTBUF+15D
            61 0 00004              SAL  0 4
05707       74 0 42032              EXF  0 42032
            74 7 42000              EXF  7 42000
05710       74 4 05267              EXF  4 OUTBUF
            74 7 42000              EXF  7 42000
05711       75 0 05705              SLJ  0 OUTPUT2
            50 0 00000              ENI  0 0
05712       75 0 00000   MSG        SLJ  0 0
            50 5 00000              ENI  5 0
05713       12 5 00000              LDA  5 0
            20 5 05270              STA  5 OUTBUF+1
05714       54 5 00000              ISK  5 0
            75 0 05713              SLJ  0 /-1
05715       75 4 05705              SLJ  4 OUTPUT2
            50 0 00000              ENI  0 0
05716       75 0 05712              SLJ  0 MSG
            50 0 00000              ENI  0 0
05717       75 0 00000   CLRBUF     SLJ  0 0
            12 0 06011              LDA  0 DBSP
05720       20 0 05267              STA  0 OUTBUF
            50 5 00015              ENI  5 13D
05721       12 0 05252              LDA  0 SPACE
            20 5 05270              STA  5 OUTBUF+1
05722       55 5 05721              IJP  5 /-1
            75 0 05717              SLJ  0 CLRBUF
05723       75 0 00000   ORCOUNT    SLJ  0 0
            10 0 00000              ENA  0 0
05724       20 0 06063              STA  0 ORCNT
            04 0 00000              ENQ  0 0
05725       16 6 05267              LDQ  6 OUTBUF
            50 4 00007              ENI  4 7
05726       07 0 00006              LLS  0 6
            50 0 00000              ENI  0 0
05727       64 0 06106              EQS  0 PLUS
            75 0 05731              SLJ  0 /+2
05730       72 0 06063              RAO  0 ORCNT
            50 0 00000              ENI  0 0
05731       10 0 00000              ENA  0 0
            55 4 05726              IJP  4 /-3
05732       55 6 05725              IJP  6 /-5
            72 0 06063              RAO  0 ORCNT
05733       75 0 05723              SLJ  0 ORCOUNT
            50 0 00000              ENI  0 0
05734       75 0 00000   OUTPIN     SLJ  0 0
            53 2 06067              LIL  2 WAIT
05735       16 0 06071              LDQ  0 SMASK
            44 0 05271              LDL  0 OUTBUF+2
05736       15 0 06071              SUB  0 SMASK
            22 0 05752              AJP  0 TYP3
05737       16 0 06111              LDQ  0 TMASK
            44 0 05271              LDL  0 OUTBUF+2
05740       22 1 05752              AJP  1 TYP3
            02 0 00001              QRS  0 1
05741       44 0 05271              LDL  0 OUTBUF+2
            22 1 05763              AJP  1 TYP2
05742       10 0 00001              ENA  0 1
            75 4 05771              SLJ  4 INPIN
05743       10 0 00014              ENA  0 12D
            50 0 00000              ENI  0 0
05744       05 0 00030   MID        ALS  0 24D
            70 2 16000              RAD  2 ALFA
05745       12 0 06070              LDA  0 FFFLG
            22 0 05750              AJP  0 /+3
05746       12 0 05455              LDA  0 BIT48
            20 2 16001              STA  2 ALFA+1
05747       10 0 00000              ENA  0 0
            20 0 06070              STA  0 FFFLG
```

```
05750     51 2 00022                  ENI    2 22
          57 2 06067                  SIL    2 WAIT
05751     75 0 05734                  SLJ    0 OUTPIN
          50 0 00000                  ENI    0 0
05752     04 0 00077     TYP3         ENQ    0 77
          44 0 05270                  LDL    0 OUTBUF+1
05753     64 0 06114                  EQS    0 PTA
          75 0 05756                  SLJ    0 /+3
05754     10 0 00001                  ENA    0 1
          75 4 05771                  SLJ    4 INPIN
05755     10 0 00004                  ENA    0 4D
          75 0 05744                  SLJ    0 MID
05756     64 0 06115                  EQS    0 PTB
          75 0 05761                  SLJ    0 /+3
05757     10 0 00005                  ENA    0 5
          75 4 05771                  SLJ    4 INPIN
05760     10 0 00010                  ENA    0 8D
          75 0 05744                  SLJ    0 MID
05761     10 0 00011                  ENA    0 9D
          75 4 05771                  SLJ    4 INPIN
05762     75 0 05743                  SLJ    0 MID-1
          50 0 00000                  ENI    0 0
05763     04 0 00077     TYP2         ENQ    0 77
          44 0 05270                  LDL    0 OUTBUF+1
05764     64 0 06114                  EQS    0 PTA
          75 0 05767                  SLJ    0 /+3
05765     10 0 00001                  ENA    0 1
          75 4 05771                  SLJ    4 INPIN
05766     10 0 00006                  ENA    0 6
          75 0 05744                  SLJ    0 MID
05767     10 0 00007                  ENA    0 7
          75 4 05771                  SLJ    4 INPIN
05770     75 0 05743                  SLJ    0 MID-1
          50 0 00000                  ENI    0 0
05771     75 0 00000     INPIN        SLJ    0 0
          05 0 00036                  ALS    0 30D
05772     70 2 16000                  RAD    2 ALFA
          75 0 05771                  SLJ    0 INPIN
05773     75 0 00000     MAKEX        SLJ    0 0
          12 0 05301                  LDA    0 OUTBUF+10D
05774     20 0 06066                  STA    0 HOLD
          41 0 06112                  SCL    0 HIMASK
05775     07 0 00060                  LLS    0 48D
          12 0 05241                  LDA    0 TEMP
05776     75 4 06001                  SLJ    4 ENTER
          50 0 00000                  ENI    0 0
05777     12 0 05252                  LDA    0 SPACE
          20 0 05301                  STA    0 OUTBUF+10D
06000     75 0 05773                  SLJ    0 MAKEX
          50 0 00000                  ENI    0 0
06001     75 0 00000     ENTER        SLJ    0 0
          57 6 06065                  SIL    6 STORE
06002     53 6 06064                  LIL    6 COUNT
          20 6 10000                  STA    6 ARGUE
06003     21 6 13000                  STQ    6 VALUE
          50 0 00000                  ENI    0 0
06004     54 6 02777                  ISK    6 2777
          75 0 06006                  SLJ    0 /+2
06005     04 0 00000                  ENQ    0 0
          75 0 06007                  SLJ    0 /+2
06006     50 0 00000                  ENI    0 0
          57 6 06064                  SIL    6 COUNT
06007     53 6 06065                  LIL    6 STORE
          75 0 06001                  SLJ    0 ENTER
06010     01 2 02020     PAGEJ        BCD      /1
          20 2 02020
06011     12 2 02020     DBSP         BCD      /0
          20 2 02020
06012     00 0 00000     LNGTH1       DEC      7
          00 0 00007
06013     00 0 00000     LNGTH2       DEC      4
          00 0 00004
06014     00 0 00000     LNGTH3       DEC      5
```

```
         00 0 00005 .
06015    00 0 00000    RFR00    OCT    1
         00 0 00001
06016    00 0 00000    RFR01    OCT    12
         00 0 00012
06017    00 0 00000    RFR02    OCT    144
         00 0 00144
06020    00 0 00000    RFR03    OCT    1750
         00 0 01750
06021    20 2 02020    MASK     OCT    2020202020202000
         20 2 02000
06022    20 2 02020             OCT    2020202020200000
         20 2 00000
06023    20 2 02020             OCT    2020202020000000
         20 0 00000
06024    20 2 02020             OCT    2020202000000000
         00 0 00000
06025    00 0 00000    DOUB     DEC    9
         00 0 00011
06026    00 0 00000    TRIP     DEC    14
         00 0 00016
06027    00 0 00000    ICOUNT   BSS    18D
         00 0 00000
06051    00 0 00000    FCOUNT   BSS    9D
         00 0 00000
06062    00 0 00000    OUTCNT   BSS    1
         00 0 00000
06063    00 0 00000    ORCNT    BSS    1
         00 0 00000
06064    00 0 00000    COUNT    BSS    1
         00 0 00000
06065    00 0 00000    STORE    BSS    1
         00 0 00000
06066    00 0 00000    HOLD     BSS    1
         00 0 00000
06067    00 0 00000    WAIT     BSS    1
         00 0 00000
06070    00 0 00000    FFFLG    BSS    1
         00 0 00000
06071    00 0 02200    SMASK    OCT    220000000000
         00 0 00000
06072    20 2 00121    ATHIRD   OCT    2020012103202020
         03 2 02020
06073    20 2 00221    BTHIRD   OCT    2020022103202020
         03 2 02020
06074    20 2 00121    AHALF    OCT    2020012102202020
         02 2 02020
06075    00 0 00000    QUINT    OCT    5
         00 0 00005
06076    00 0 00000    QUAD     OCT    4
         00 0 00004
06077    00 0 00000    TRIO     OCT    3
         00 0 00003
06100    00 0 00000    DUO      OCT    2
         00 0 00002
06101    00 0 00000    OUTEND   OCT    7
         00 0 00007
06102    00 0 00000    SEXT     OCT    6
         00 0 00006
06103    00 0 00000    TAGE     OCT    54542020
         54 5 42020
06104    00 0 00054    OUITE    OCT    5454542020
         54 5 42020
06105    00 0 05454    INE      OCT    545454542020
         54 5 42020
06106    00 0 00000    PLUS     OCT    60
         00 0 00060
06107    00 0 00000    ZERO     OCT    12
         00 0 00012
06110    00 0 00000    CMASK    OCT    33000000
         33 0 00000
06111    00 0 00004    TMASK    OCT    400000000
         00 0 00000
```

```
06112        77 7 77777   HIMASK    OCT      777777770000000O
             00 0 00000
06113        00 0 00000   LOMASK    OCT      77777777
             77 7 77777
06114        00 0 00000   PTA       OCT      61
             00 0 00061
06115        00 0 00000   PTE       OCT      62
             00 0 00062
06116        20 2 02001   CARD      BCD      /    11
             01 2 02020
06117        20 2 02001             BCD      /    12
             02 2 02020
06120        20 2 02001             BCD      /    13
             03 2 02020
06121        20 2 02001             BCD      /    14
             04 2 02020
06122        20 2 02001             BCD      /    15
             05 2 02020
06123        20 2 02001             BCD      /    16
             06 2 02020
06124        20 2 02003             BCD      /    31
             01 2 02020
06125        20 2 02003             BCD      /    32
             02 2 02020
06126        20 2 02003             BCD      /    33
             03 2 02020
06127        20 2 02002             BCD      /    21
             01 2 02020
06130        20 2 02002             BCD      /    22
             02 2 02020
06131        20 2 02002             BCD      /    23
             03 2 02020
06132        20 2 02002             BCD      /    24
             04 2 02020
06133        20 2 02012             BCD      /    01
             01 2 02020
06134        20 2 02006             BCD      /    61
             01 2 02020
06135        20 2 02006             BCD      /    62
             02 2 02020
06136        20 2 02203             BCD      /   S36
             06 2 02020
06137        20 2 02212             BCD      /   S04
             04 2 02020
06140        24 2 02220   HEAD1     BCD      /U S NAVA
             45 6 12561
06141        43 2 04746             BCD      /L POST G
             22 2 32067
06142        51 6 16424             BCD      /RADUATE
             61 2 36520
06143        22 6 37046             BCD      /SCHOOL
             46 4 32020
06144        20 2 06461             BCD      /  DATA P
             23 6 12047
06145        51 4 66365             BCD      /ROCESSIN
             22 2 27145
06146        67 2 04361             BCD      /G LABORA
             62 4 65161
06147        23 4 65130             BCD      /TORY
             20 2 02020
06150        20 2 02020   HEAD2     BCD      /
             20 2 02020
06151        63 4 64447             BCD      /COMPILAT
             71 4 36123
06152        71 4 64520             BCD      /ION OF C
             46 6 62063
06153        61 5 16420             BCD      /ARD ASSI
             61 2 22271
06154        67 4 54465             BCD      /GNMENTS
             45 2 32220
06155        20 2 02020   HEAD3     BCD      /
             20 2 02020
06156        63 6 15164             BCD      /CARD TYP
```

```
         20 2 33047
06157    65 2 02020          BCD    /E
         20 2 02020
06160    20 2 02020          BCD    /
         20 2 02020
06161    45 2 44462          BCD    /NUMBER O
         65 5 12046
06162    66 2 06361          BCD    /F CARDS
         51 6 42220
06163    50 1 00000  PASS4   ENI    1 0
         50 2 00000          ENI    2 0
06164    50 3 00000          ENI    3 0
         50 4 00000          ENI    4 0
06165    50 6 00002          ENI    6 2
         10 0 00000          ENA    0 0
06166    20 0 06027          STA    0 ICOUNT
         20 0 06067          STA    0 WAIT
06167    20 0 06066          STA    0 HOLD
         75 4 05202          SLJ    4 FILL
06170    12 0 06010          LDA    0 PAGEJ
         20 0 05267          STA    0 OUTBUF
06171    75 4 05705          SLJ    4 OUTPUT2
         50 0 00000          ENI    0 0
06172    75 4 05717          SLJ    4 CLRBUF
         50 0 00000          ENI    0 0
06173    10 0 06140          ENA    0 HEAD1
         60 0 05713          SAU    0 MSG+1
06174    12 0 06012          LDA    0 LNGTH1
         60 0 05714          SAU    0 MSG+2
06175    75 4 05712          SLJ    4 MSG
         50 0 00000          ENI    0 0
06176    75 4 05717          SLJ    4 CLRBUF
         50 0 00000          ENI    0 0
06177    10 0 06560          ENA    0 HEAD4
         60 0 05713          SAU    0 MSG+1
06200    12 0 06556          LDA    0 LNGTH4
         60 0 05714          SAU    0 MSG+2
06201    75 4 05712          SLJ    4 MSG
         50 0 00000          ENI    0 0
06202    75 0 06206          SLJ    0 ONLY
         50 0 00000          ENI    0 0
06203    75 4 05202  NXTP    SLJ    4 FILL
         50 0 00000          ENI    0 0
06204    12 0 06010          LDA    0 PAGEJ
         20 0 05267          STA    0 OUTBUF
06205    75 4 05705          SLJ    4 OUTPUT2
         50 0 00000          ENI    0 0
06206    75 4 05717  ONLY    SLJ    4 CLRBUF
         50 0 00000          ENI    0 0
06207    10 0 06565          ENA    0 HEAD5
         60 0 05713          SAU    0 MSG+1
06210    12 0 06557          LDA    0 LNGTH5
         60 0 05714          SAU    0 MSG+2
06211    75 4 05712          SLJ    4 MSG
         50 0 00000          ENI    0 0
06212    75 4 05717  WLINE   SLJ    4 CLRBUF
         50 0 00000          ENI    0 0
06213    75 4 06223          SLJ    4 GET
         50 0 00000          ENI    0 0
06214    75 4 05705          SLJ    4 OUTPUT2
         50 0 00000          ENI    0 0
06215    12 0 05277          LDA    0 OUTBUF+80
         41 0 05252          SCL    0 SPACE
06216    22 1 06221          AJP    1 /+3
         50 0 00000          ENI    0 0
06217    74 0 42003          EXF    0 42003
         74 7 42000          EXF    7 42000
06220    74 0 42005          EXF    0 42005
         76 0 05000          SLS    0 5000
06221    54 6 00043          ISK    6 35D
         75 0 06212          SLJ    0 WLINE
06222    75 0 06203          SLJ    0 NXTP
         50 0 00000          ENI    0 0
```

```
06223    75 0 00000   GET      SLJ   0 0
         10 2 00000            ENA   2 0
06224    22 1 06264            AJP   1 PREP
         12 0 06027            LDA   0 ICOUNT
06225    22 1 06321            AJP   1 UDAT
         12 3 16000            LDA   3 ALFA
06226    01 0 00036            ARS   0 30D
         20 0 06611            STA   0 PINNI
06227    10 0 00001            ENA   0 1
         20 0 06027            STA   0 ICOUNT
06230    51 1 00001   GOT      INI   1 1
         16 0 06113            LDQ   0 LCMASK
06231    44 1 16000            LDL   1 ALFA
         20 2 06603            STA   2 AND
06232    36 1 16001            SSK   1 ALFA+1
         75 0 06235            SLJ   0 PICK
06233    22 0 06230            AJP   0 GOT
         51 2 00001            INI   2 1
06234    75 0 06240            SLJ   0 COMPUT
         50 0 00000            ENI   0 0
06235    22 0 06237   PICK     AJP   0 /+2
         51 2 00001            INI   2 1
06236    75 0 06230            SLJ   0 GOT
         50 0 00000            ENI   0 0
06237    10 0 00000            ENA   0 0
         20 0 06027            STA   0 ICOUNT
06240    57 2 06066   COMPUT   SIL   2 HOLD
         10 2 00000            ENA   2 0
06241    22 0 06322            AJP   0 LOOK
         16 0 06113            LDQ   0 LCMASK
06242    44 3 16000            LDL   3 ALFA
         20 0 06602            STA   0 IAND
06243    55 2 06244            IJP   2 /+1
         75 0 06250            SLJ   0 BAT
06244    12 2 06603            LDA   2 AND
         75 4 06504            SLJ   4 SEARCHI
06245    50 0 00000            ENI   0 0
         02 0 00006            QRS   0 6
06246    21 2 06621            STQ   2 LOCNT
         75 4 06511            SLJ   4 DECOUT
06247    20 2 06612            STA   2 PINNO
         75 0 06243            SLJ   0 /-4
06250    16 0 06113   BAT      LDQ   0 LCMASK
         44 3 16000            LDL   3 ALFA
06251    75 4 06504            SLJ   4 SEARCHI
         50 0 00000            ENI   0 0
06252    02 0 00006            QRS   0 6
         21 0 06620            STQ   0 OLOC
06253    12 0 06611            LDA   0 PINNI
         11 0 00001            INA   0 1
06254    05 0 00036            ALS   0 30D
         17 0 06743            LDC   0 IMASK
06255    43 3 16000            SSU   3 ALFA
         20 3 16000            STA   3 ALFA
06256    50 0 00000            ENI   0 0
         04 0 00000            ENQ   0 0
06257    12 0 06747            LDA   0 INDIC
         20 0 05270            STA   0 OUTPUT+1
06260    53 2 06066            LIL   2 HOLD
         75 4 06327            SLJ   4 BEST
06261    12 0 06027            LDA   0 ICOUNT
         22 1 06264            AJP   1 PREP
06262    51 3 00022            INI   3 22
         56 3 06263            SIU   3 /+1
06263    50 1 00000            ENI   1 0
         50 0 00000            ENI   0 0
06264    51 2 77776   PREP     INI   2 -1
         57 6 05311            SIL   6 BETA
06265    04 0 00000            ENQ   0 0
         12 2 06717            LDA   2 TABLE
06266    07 0 00006            LLS   0 6
         20 0 05246            STA   0 TEMP+5
06267    21 0 05245            STQ   0 TEMP+4
```

```
        53 6 05245          LIL  6 TEMP+4
06270   12 6 06611          LDA  6 PINNI
        22 0 06275          AJP  0 /+5
06271   75 4 06526          SLJ  4 CNVT
        50 0 00000          ENI  0 0
06272   03 0 00022          LRS  0 18D
        12 6 06620          LDA  6 OLOC
06273   14 0 06737          ADD  0 PRMSK
        07 0 00022          LLS  0 18D
06274   75 0 06276          SLJ  0 /+2
        50 0 00000          ENI  0 0
06275   12 6 06602          LDA  6 IAND
        14 0 06740          ADD  0 UPSPA
06276   20 0 05273          STA  0 OUTBUF+4
        50 0 00000          ENI  0 0
06277   12 6 06602          LDA  6 IAND
        14 0 06741          ADD  0 TCSPA
06300   20 0 05277          STA  0 OUTBUF+8D
        12 0 05246          LDA  0 TEMP+5
06301   04 0 00000          ENQ  0 0
        07 0 00006          LLS  0 6
06302   21 0 05245          STQ  0 TEMP+4
        53 6 05245          LIL  6 TEMP+4
06303   12 6 06611          LDA  6 PINNI
        22 0 06310          AJP  0 /+5
06304   75 4 06526          SLJ  4 CNVT
        50 0 00000          ENI  0 0
06305   03 0 00022          LRS  0 18D
        12 6 06620          LDA  6 OLOC
06306   14 0 06737          ADD  0 PRMSK
        07 0 00022          LLS  0 18D
06307   75 0 06311          SLJ  0 /+2
        50 0 00000          ENI  0 0
06310   12 6 06602          LDA  6 IAND
        14 0 06740          ADD  0 UPSPA
06311   20 0 05271          STA  0 OUTBUF+2
        50 0 00000          ENI  0 0
06312   12 6 06602          LDA  6 IAND
        14 0 06740          ADD  0 UPSPA
06313   05 0 00014          ALS  0 12D
        20 0 05276          STA  0 OUTBUF+7
06314   16 0 06113          LDQ  0 LOMASK
        44 2 06717          LDL  2 TABLE
06315   75 4 06476          SLJ  4 WIRE
        50 0 00000          ENI  0 0
06316   20 0 05302          STA  0 OUTBUF+11D
        12 0 06601          LDA  0 INCRCS
06317   20 0 05303          STA  0 OUTBUF+12D
        53 6 05311          LIL  6 BETA
06320   75 0 06223          SLJ  0 GET
        50 0 00000          ENI  0 0
06321   72 0 06611   UDAT   RAO  0 PINNI
        75 0 06230          SLJ  0 GOT
06322   12 3 16000   LOOK   LDA  3 ALFA
        22 0 06223          AJP  0 GET
06323   12 3 16001          LDA  3 ALFA+1
        22 1 06325          AJP  1 /+2
06324   12 0 07227          LDA  0 CLOCK
        20 0 05277          STA  0 OUTBUF+8D
06325   51 3 00022          INI  3 22
        56 3 06326          SIU  3 /+1
06326   50 1 00000          ENI  1 0
        75 0 06223          SLJ  0 GET
06327   75 0 00000   BEST   SLJ  0 0
        57 6 06065          SIL  6 STORE
06330   10 0 00000          ENA  0 0
        50 6 00107          ENI  6 71D
06331   20 6 06627          STA  6 SINK
        55 6 06331          IJP  6 /
06332   20 0 05253          STA  0 FLAG
        75 4 06401          SLJ  4 POSITS
06333   55 2 06332          IJP  2 /-1
        12 0 06066          LDA  0 HOLD
```

```
06334     60 0 06451            SAU  0 DIAG+11D
          11 0 77776            INA  0 -1
06335     60 0 06452            SAU  0 DIAG+12D
          75 4 06436            SLJ  4 DIAG
06336     12 0 06066            LDA  0 HOLD
          57 2 05245            SIL  2 TEMP+4
06337     11 0 77776            INA  0 -1
          60 0 06376            SAU  0 ACCEPT+3
06340     16 0 07224   MAINL    LDQ  0 BLOT
          51 2 77776            INI  2 -1
06341     50 0 00000            ENI  0 0
          44 2 06654            LDL  2 CHAIR
06342     22 1 06343            AJP  1 /+1
          55 2 06341            IJP  2 /-1
06343     04 6 00000            ENQ  6 0
          23 1 06351            QJP  1 EARLY
06344     07 0 00006            LLS  0 6
          05 0 00006            ALS  0 6
06345     20 0 06735            STA  0 END1
          20 0 06726            STA  0 SUBTRE
06346     21 0 06736            STQ  0 END1+1
          21 0 06727            STQ  0 SUBTRE+1
06347     50 4 00002            ENI  4 2
          57 4 06067            SIL  4 WAIT
06350     75 0 06373            SLJ  0 ACCEPT
          50 0 00000            ENI  0 0
06351     04 0 00000   EARLY    ENQ  0 0
          07 0 00006            LLS  0 6
06352     05 0 00006            ALS  0 6
          50 0 00000            ENI  0 0
06353     64 4 06735   DOG      EQS  4 END1
          75 0 06361            SLJ  0 RAT
06354     57 4 05247            SIL  4 TEMP+6
          50 0 00000            ENI  0 0
06355     07 0 00060            LLS  0 48D
          53 4 06067            LIL  4 WAIT
06356     64 4 06726            EQS  4 SUBTRE
          75 0 06367            SLJ  0 WEDO
06357     10 0 00000            ENA  0 0
          20 2 06654            STA  2 CHAIR
06360     20 0 05253            STA  0 FLAG
          75 0 06340            SLJ  0 MAINL
06361     53 4 05253   RAT      LIL  4 FLAG
          55 4 06365            IJP  4 SKIP
06362     07 0 00060            LLS  0 48D
          50 4 00001            ENI  4 1
06363     57 4 05253            SIL  4 FLAG
          50 4 00002            ENI  4 2
06364     75 0 06353            SLJ  0 DOG
          50 0 00000            ENI  0 0
06365     57 4 05253   SKIP     SIL  4 FLAG
          50 4 00002            ENI  4 2
06366     75 0 06340            SLJ  0 MAINL
          50 0 00000            ENI  0 0
06367     53 4 06067   WEDO     LIL  4 WAIT
          20 4 06726            STA  4 SUBTRE
06370     53 4 05247            LIL  4 TEMP+6
          20 4 06735            STA  4 END1
06371     72 0 06067            RAO  0 WAIT
          10 0 00000            ENA  0 0
06372     20 0 05253            STA  0 FLAG
          50 0 00000            ENI  0 0
06373     12 2 06654   ACCEPT   LDA  2 CHAIR
          20 6 06717            STA  6 TABLE
06374     10 0 00000            ENA  0 0
          20 2 06654            STA  2 CHAIR
06375     50 4 00002            ENI  4 2
          53 2 05245            LIL  2 TEMP+4
06376     54 6 00000            ISK  6 0
          75 0 06340            SLJ  0 MAINL
06377     53 2 06066            LIL  2 HOLD
          53 6 06065            LIL  6 STORE
06400     75 0 06327            SLJ  0 BEST
```

```
          50 0 00000            ENI  0 0
06401     75 0 00000   POSITS   SLJ  0 0
          04 0 00077            ENQ  0 77
06402     44 2 06620            LDL  2 OLOC
          22 0 06434            AJP  0 NULOT
06403     64 0 06107            EQS  0 ZERO
          75 0 06405            SLJ  0 /+2
06404     10 0 00000            ENA  0 0
          50 0 00000            ENI  0 0
06405     20 0 05246            STA  0 TEMP+5
          06 0 00006            QLS  0 6
06406     44 2 06620            LDL  2 OLCC
          01 0 00006            ARS  0 6
06407     64 0 06107            EQS  0 ZERO
          75 0 06411            SLJ  0 /+2
06410     10 0 00000            ENA  0 0
          50 0 00000            ENI  0 0
06411     24 0 06107            MUI  0 ZERO
          70 0 05246            RAD  0 TEMP+5
06412     24 0 06746            MUI  0 DCOL
          20 2 06701            STA  2 HOR
06413     16 0 07221            LDQ  0 GLCP
          44 2 06620            LDL  2 OLCC
06414     22 1 06416            AJP  1 /+2
          10 0 00011            ENA  0 9D
06415     20 0 05246            STA  0 TEMP+5
          75 0 06417            SLJ  0 /+2
06416     10 0 00000            ENA  0 0
          20 0 05246            STA  0 TEMP+5
06417     16 0 07222            LDQ  0 GLUM
          44 2 06620            LDL  2 OLCC
06420     22 0 06425            AJP  0 /+5
          10 0 00007            ENA  0 7
06421     70 0 05246            RAD  0 TEMP+5
          04 0 10000            ENQ  0 10000
06422     44 2 06620            LDL  2 OLCC
          22 0 06424            AJP  0 /+2
06423     10 0 00002            ENA  0 2
          75 0 06427            SLJ  0 /+4
06424     10 0 00001            ENA  0 1
          75 0 06427            SLJ  0 /+3
06425     16 0 07225            LDQ  0 BLUB
          44 2 06620            LDL  2 OLCC
06426     01 0 00014            ARS  0 12D
          50 0 00000            ENI  0 0
06427     70 0 05246            RAD  0 TEMP+5
          24 0 06744            MUI  0 DROW
06430     20 0 05246            STA  0 TEMP+5
          12 2 06611            LDA  2 PINNI
06431     24 0 06745            MUI  0 DPIN
          14 0 05246            ADD  0 TEMP+5
06432     20 2 06710            STA  2 VER
          10 0 00000            ENA  0 0
06433     75 0 06401            SLJ  0 POSITS
          50 0 00000            ENI  0 0
06434     20 2 06701   NULOT    STA  2 HOR
          20 2 06710            STA  2 VER
06435     10 0 00000            ENA  0 0
          75 0 06401            SLJ  0 POSITS
06436     75 0 00000   DIAG     SLJ  0 0
          57 3 05246            SIL  3 TEMP+5
06437     50 3 00000            ENI  3 0
          50 6 00001            ENI  6 1
06440     12 6 06701            LDA  6 HOR
          15 2 06701            SUB  2 HOR
06441     20 0 05245            STA  0 TEMP+4
          24 0 05245            MUI  0 TEMP+4
06442     20 0 05245            STA  0 TEMP+4
          12 6 06710            LDA  6 VER
06443     15 2 06710            SUB  2 VER
          20 0 05247            STA  0 TEMP+6
06444     24 0 05247            MUI  0 TEMP+6
          70 0 05245            RAD  0 TEMP+4
```

```
06445    10 6 00000               ENA  6 0
         05 0 00006               ALS  0 6
06446    11 2 00000               INA  2 0
         05 0 00044               ALS  0 36D
06447    14 0 05245               ADD  0 TEMP+4
         20 3 06627               STA  3 SINK
06450    51 3 00001               INI  3 1
         50 0 00000               ENI  0 0
06451    54 6 00000               ISK  6 0
         75 0 06440               SLJ  0 DIAG+2
06452    54 2 00000               ISK  2 0
         75 0 06454               SLJ  0 /+2
06453    51 3 77776               INI  3 -1
         75 0 06456               SLJ  0 ORDER
06454    57 2 05245               SIL  2 TEMP+4
         53 6 05245               LIL  6 TEMP+4
06455    51 6 00001               INI  6 1
         75 0 06440               SLJ  0 DIAG+2
06456    57 3 05245   ORDER       SIL  3 TEMP+4
         72 0 05245               RAO  0 TEMP+4
06457    16 0 07223               LDQ  0 BLAM
         10 3 00000               ENA  3 0
06460    11 0 06627               INA  0 SINK
         61 0 06462               SAL  0 /+2
06461    60 0 06471               SAU  0 VARI
         50 0 00000               ENI  0 0
06462    53 6 05245               LIL  6 TEMP+4
         44 0 00000               LDL  0 0
06463    67 6 06627               MTH  6 SINK
         75 0 06467               SLJ  0 /+4
06464    57 6 07226               SIL  6 GOFER
         10 0 06627               ENA  0 SINK
06465    14 0 07226               ADD  0 GOFER
         60 0 06471               SAU  0 VARI
06466    44 6 06627               LDL  6 SINK
         75 0 06463               SLJ  0 /-3
06467    52 5 06471               LIU  5 VARI
         12 5 00000               LDA  5 0
06470    20 2 06654               STA  2 CHAIR
         10 0 00000               ENA  0 0
06471    20 0 00000   VARI        STA  0 0
         51 2 00001               INI  2 1
06472    55 3 06474               IJP  3 LAMP
         53 3 05246               LIL  3 TEMP+5
06473    75 0 06436               SLJ  0 DIAG
         50 0 00000               ENI  0 0
06474    53 5 06462   LAMP        LIL  5 ORDER+4
         56 5 06471               SIU  5 VARI
06475    75 0 06462               SLJ  0 ORDER+4
         50 0 00000               ENI  0 0
06476    75 0 00000   WIRE        SLJ  0 0
         50 0 00000               ENI  0 0
06477    57 6 06065               SIL  6 STORE
         50 6 00124               ENI  6 84D
06500    65 6 07074               THS  6 APPX
         75 0 06502               SLJ  0 /+2
06501    12 6 06750               LDA  6 TYPE
         75 0 06503               SLJ  0 /+2
06502    12 0 07220               LDA  0 MAX
         50 0 00000               ENI  0 0
06503    53 6 06065               LIL  6 STORE
         75 0 06476               SLJ  0 WIRE
06504    75 0 00000   SEARCHI     SLJ  0 0
         04 0 00000               ENQ  0 0
06505    57 6 06065               SIL  6 STORE
         53 6 06064               LIL  6 COUNT
06506    64 6 10000               EQS  6 ARGUE
         75 0 06510               SLJ  0 /+2
06507    16 6 13000               LDQ  6 VALUE
         50 0 00000               ENI  0 0
06510    53 6 06065               LIL  6 STORE
         75 0 06504               SLJ  0 SEARCHI
06511    75 0 00000   DECOUT      SLJ  0 0
```

```
        57 6 06065              SIL   6 STORE
06512   53 6 05242              LIL   6 TEMP+1
        16 0 06113              LDQ   0 LOMASK
06513   66 6 16000              MEQ   6 ALFA
        75 0 06524              SLJ   0 /+9D
06514   16 0 06742              LDQ   0 OMASK
        44 6 16000              LDL   6 ALFA
06515   22 1 06517              AJP   1 /+2
        12 2 06603              LDA   2 AND
06516   16 0 06113              LDQ   0 LOMASK
        75 0 06513              SLJ   0 /-3
06517   01 0 00030              ARS   0 24D
        20 0 06067              STA   0 WAIT
06520   11 0 77776              INA   0 -1
        05 0 00030              ALS   0 24D
06521   17 0 06742              LQC   0 OMASK
        43 6 16000              SSU   6 ALFA
06522   20 6 16000              STA   6 ALFA
        12 0 06067              LDA   0 WAIT
06523   75 0 06525              SLJ   0 /+2
        50 0 00000              ENI   0 0
06524   10 0 00000              ENA   0 0
        50 0 00000              ENI   0 0
06525   53 6 06065              LIL   6 STORE
        75 0 06511              SLJ   0 DECOUT
06526   75 0 00000     CNVT     SLJ   0 0
        57 6 06065              SIL   6 STORE
06527   50 6 00011              ENI   6 9D
        04 0 00077              ENQ   0 77
06530   66 6 06542              MEQ   6 BACK
        75 0 06532              SLJ   0 /+2
06531   75 0 06537              SLJ   0 /+6
        50 0 00000              ENI   0 0
06532   15 0 06541              SUB   0 FORTN
        22 3 06534              AJP   3 /+2
06533   12 0 06555              LDA   0 BACK+11D
        75 0 06540              SLJ   0 RAW
06534   11 0 00001              INA   0 1
        22 3 06536              AJP   3 /+2
06535   12 0 06554              LDA   0 BACK+10D
        75 0 06540              SLJ   0 RAW
06536   12 0 06553              LDA   0 BACK+9D
        75 0 06540              SLJ   0 RAW
06537   12 6 06542              LDA   6 BACK
        50 0 00000              ENI   0 0
06540   53 6 06065     RAW      LIL   6 STORE
        75 0 06526              SLJ   0 CNVT
06541   00 0 00000     FORTN    OCT     14
        00 0 00014
06542   00 0 00000     BACK     OCT     401201
        00 4 01201
06543   00 0 00000              OCT     401202
        00 4 01202
06544   00 0 00000              OCT     401203
        00 4 01203
06545   00 0 00000              OCT     401204.
        00 4 01204
06546   00 0 00000              OCT     401205
        00 4 01205
06547   00 0 00000              OCT     401206
        00 4 01206
06550   00 0 00000              OCT     401207
        00 4 01207
06551   00 0 00000              OCT     401210
        00 4 01210
06552   00 0 00000              OCT     401211
        00 4 01211
06553   00 0 00000              OCT     400112
        00 4 00112
06554   00 0 00000              OCT     400101
        00 4 00101
06555   00 0 00000              OCT     400102
        00 4 00102
```

```
06556    00 0 00000  . LNGTH4    DEC    4
         00 0 00004
06557    00 0 00000    LNGTH5    DEC    11D
         00 0 00013
06560    20 2 02020    HEAD4     BCD    /
         20 2 02020
06561    71 4 52365              BCD    /INTER CA
         51 2 06361
06562    51 6 42026              BCD    /RD WIRIN
         71 5 17149
06563    67 2 02361              BCD    /G TABULA
         62 2 44361
06564    23 7 14645              BCD    /TION
         20 2 02020
06565    20 2 02020    HEAD5     BCD    /
         20 2 02020
06566    20 2 04651              BCD    /  ORIGIN
         71 6 77145
06567    20 2 02020              BCD    /
         20 2 02020
06570    64 6 52223              BCD    /DESTINAT
         71 4 56123
06571    71 4 64520              BCD    /ICN
         20 2 02020
06572    20 2 02020              BCD    /
         20 2 02020
06573    20 2 02064              BCD    /   DESIG
         65 2 27167
06574    45 6 12371              BCD    /NATIONS
         46 4 52220
06575    20 2 02020              BCD    /
         20 2 02020
06576    20 2 02020              BCD    /
         20 2 02020
06577    26 7 15165              BCD    /WIRE LEN
         20 4 36545
06600    67 2 37020              BCD    /GTH
         20 2 02020
06601    71 4 56370    INCHES    BCD    /INCHES
         65 2 22020
06602    00 0 00000    IAND      BSS    1
         00 0 00000
06603    00 0 00000    AND       BSS    6
         00 0 00000
06611    00 0 00000    PINNI     BSS    1
         00 0 00000
06612    00 0 00000    PINNO     BSS    6
         00 0 00000
06620    00 0 00000    OLOC      BSS    1
         00 0 00000
06621    00 0 00000    LOCAT     BSS    6
         00 0 00000
06627    00 0 00000    SINK      BSS    21D
         00 0 00000
06654    00 0 00000    CHAIR     BSS    21D
         00 0 00000
06701    00 0 00000    HOR       BSS    7
         00 0 00000
06710    00 0 00000    VER       BSS    7
         00 0 00000
06717    00 0 00000    TABLE     BSS    7
         00 0 00000
06726    00 0 00000    SUBTRE    BSS    7
         00 0 00000
06735    00 0 00000    END1      BSS    2
         00 0 00000
06737    00 0 00020    PRMSK     OCT    2020000000
         20 0 00000
06740    20 2 02020    UPSPA     OCT    202020200000000
         00 0 00000
06741    23 4 62020    TOSPA     OCT    234620200000000
         00 0 00000
06742    00 0 00077    OMASK     OCT    7700000000
```

```
                 00 0 00000
06743            00 0 07700    IMASK     OCT     770000000000
                 00 0 00000
06744            00 0 00000    DROW      DEC     38
                 00 0 00046
06745            00 0 00000    DPIN      DEC     2
                 00 0 00002
06746            00 0 00000    DCOL      DEC     5
                 00 0 00005
06747            20 2 02054    INDIG     BCD     /     *
                 20 2 02020
06750            04 0 32020    TYPE      BCD     /43
                 20 2 02020
06751            04 0 22001              BCD     /42 1/2
                 21 0 22020
06752            04 0 22020              BCD     /42
                 20 2 02020
06753            04 0 12001              BCD     /41 1/2
                 21 0 22020
06754            04 0 12020              BCD     /41
                 20 2 02020
06755            04 1 22001              BCD     /40 1/2
                 21 0 22020
06756            04 1 22020              BCD     /40
                 20 2 02020
06757            03 1 12001              BCD     /39 1/2
                 21 0 22020
06760            03 1 12020              BCD     /39
                 20 2 02020
06761            03 1 02001              BCD     /38 1/2
                 21 0 22020
06762            03 1 02020              BCD     /38
                 20 2 02020
06763            03 0 72001              BCD     /37 1/2
                 21 0 22020
06764            03 0 72020              BCD     /37
                 20 2 02020
06765            03 0 62001              BCD     /36 1/2
                 21 0 22020
06766            03 0 62020              BCD     /36
                 20 2 02020
06767            03 0 52001              BCD     /35 1/2
                 21 0 22020
06770            03 0 52020              BCD     /35
                 20 2 02020
06771            03 0 42001              BCD     /34 1/2
                 21 0 22020
06772            03 0 42020              BCD     /34
                 20 2 02020
06773            03 0 32001              BCD     /33 1/2
                 21 0 22020
06774            03 0 32020              BCD     /33
                 20 2 02020
06775            03 0 22001              BCD     /32 1/2
                 21 0 22020
06776            03 0 22020              BCD     /32
                 20 2 02020
06777            03 0 12001              BCD     /31 1/2
                 21 0 22020
07000            03 0 12020              BCD     /31
                 20 2 02020
07001            03 1 22001              BCD     /30 1/2
                 21 0 22020
07002            03 1 22020              BCD     /30
                 20 2 02020
07003            02 1 12001              BCD     /29 1/2
                 21 0 22020
07004            02 1 12020              BCD     /29
                 20 2 02020
07005            02 1 02001              BCD     /28 1/2
                 21 0 22020
07006            02 1 02020              BCD     /28
                 20 2 02020
```

```
07007      02 0 72001          BCD    /27 1/2
           21 0 22020
07010      02 0 72020          BCD    /27
           20 2 02020
07011      02 0 62001          BCD    /26 1/2
           21 0 22020
07012      02 0 62020          BCD    /26
           20 2 02020
07013      02 0 52001          BCD    /25 1/2
           21 0 22020
07014      02 0 52020          BCD    /25
           20 2 02020
07015      02 0 42001          BCD    /24 1/2
           21 0 22020
07016      02 0 42020          BCD    /24
           20 2 02020
07017      02 0 32001          BCD    /23 1/2
           21 0 22020
07020      02 0 32020          BCD    /23
           20 2 02020
07021      02 0 22001          BCD    /22 1/2
           21 0 22020
07022      02 0 22020          BCD    /22
           20 2 02020
07023      02 0 12001          BCD    /21 1/2
           21 0 22020
07024      02 0 12020          BCD    /21
           20 2 02020
07025      02 1 22001          BCD    /20 1/2
           21 0 22020
07026      02 1 22020          BCD    /20
           20 2 02020
07027      01 1 12001          BCD    /19 1/2
           21 0 22020
07030      01 1 12020          BCD    /19
           20 2 02020
07031      01 1 02001          BCD    /18 1/2
           21 0 22020
07032      01 1 02020          BCD    /18
           20 2 02020
07033      01 0 72001          BCD    /17 1/2
           21 0 22020
07034      01 0 72020          BCD    /17
           20 2 02020
07035      01 0 62001          BCD    /16 1/2
           21 0 22020
07036      01 0 62020          BCD    /16
           20 2 02020
07037      01 0 52001          BCD    /15 1/2
           21 0 22020
07040      01 0 52020          BCD    /15
           20 2 02020
07041      01 0 42001          BCD    /14 1/2
           21 0 22020
07042      01 0 42020          BCD    /14
           20 2 02020
07043      01 0 32001          BCD    /13 1/2
           21 0 22020
07044      01 0 32020          BCD    /13
           20 2 02020
07045      01 0 22001          BCD    /12 1/2
           21 0 22020
07046      01 0 22020          BCD    /12
           20 2 02020
07047      01 0 12001          BCD    /11 1/2
           21 0 22020
07050      01 0 12020          BCD    /11
           20 2 02020
07051      01 1 22001          BCD    /10 1/2
           21 0 22020
07052      01 1 22020          BCD    /10
           20 2 02020
07053      20 1 12001          BCD    / 9 1/2
```

```
              21 0 22020
07054         20 1 12020               BCD    / 9
              20 2 02020
07055         20 1 02001               BCD    / 8 1/2
              21 0 22020
07056         20 1 02020               BCD    / 8
              20 2 02020
07057         20 0 72001               BCD    / 7 1/2
              21 0 22020
07060         20 0 72020               BCD    / 7
              20 2 02020
07061         20 0 62001               BCD    / 6 1/2
              21 0 22020
07062         20 0 62020               BCD    / 6
              20 2 02020
07063         20 0 52001               BCD    / 5 1/2
              21 0 22020
07064         20 0 52020               BCD    / 5
              20 2 02020
07065         20 0 42001               BCD    / 4 1/2
              21 0 22020
07066         20 0 42020               BCD    / 4
              20 2 02020
07067         20 0 32001               BCD    / 3 1/2
              21 0 22020
07070         20 0 32020               BCD    / 3
              20 2 02020
07071         20 0 22001               BCD    / 2 1/2
              21 0 22020
07072         20 0 22020               BCD    / 2
              20 2 02020
07073         20 0 12001               BCD    / 1 1/2
              21 0 22020
07074         00 0 00000   APPX        DEC    284516
              01 0 53544
07075         00 0 00000               DEC    277782
              01 0 36426
07076         00 0 00000               DEC    271128
              01 0 21430
07077         00 0 00000               DEC    264556
              01 0 04554
07100         00 0 00000               DEC    258064
              00 7 70020
07101         00 0 00000               DEC    251653
              00 7 53405
07102         00 0 00000               DEC    245322
              00 7 37112
07103         00 0 00000               DEC    239072
              00 7 22740
07104         00 0 00000               DEC    232902
              00 7 06706
07105         00 0 00000               DEC    226814
              00 6 72776
07106         00 0 00000               DEC    220806
              00 6 57206
07107         00 0 00000               DEC    214879
              00 6 43537
07110         00 0 00000               DEC    209032
              00 6 30210
07111         00 0 00000               DEC    203266
              00 6 15002
07112         00 0 00000               DEC    197580
              00 6 01714
07113         00 0 00000               DEC    191975
              00 5 66747
07114         00 0 00000               DEC    186451
              00 5 54123
07115         00 0 00000               DEC    181008
              00 5 41420
07116         00 0 00000               DEC    175645
              00 5 27035
07117         00 0 00000               DEC    170363
              00 5 14573
```

```
07120      00 0 00000              DEC     165161
           00 5 02451
07121      00 0 00000              DEC     160040
           00 4 70450
07122      00 0 00000              DEC     155000
           00 4 56570
07123      00 0 00000              DEC     150040
           00 4 45030
07124      00 0 00000              DEC     145161
           00 4 33411
07125      00 0 00000              DEC     140363
           00 4 22113
07126      00 0 00000              DEC     135645
           00 4 10735
07127      00 0 00000              DEC     131008
           00 3 77700
07130      00 0 00000              DEC     126457
           00 3 66771
07131      00 0 00000              DEC     121976
           00 3 56170
07132      00 0 00000              DEC     117580
           00 3 45514
07133      00 0 00000              DEC     113266
           00 3 35162
07134      00 0 00000              DEC     109032
           00 3 24750
07135      00 0 00000              DEC     104879
           00 3 14657
07136      00 0 00000              DEC     100806
           00 3 04706
07137      00 0 00000              DEC     96814
           00 2 75056
07140      00 0 00000              DEC     92903
           00 2 65347
07141      00 0 00000              DEC     89072
           00 2 55760
07142      00 0 00000              DEC     85322
           00 2 46512
07143      00 0 00000              DEC     81653
           00 2 37365
07144      00 0 00000              DEC     78064
           00 2 30360
07145      00 0 00000              DEC     74556
           00 2 21474
07146      00 0 00000              DEC     71129
           00 2 12731
07147      00 0 00000              DEC     67782
           00 2 04306
07150      00 0 00000              DEC     64516
           00 1 76004
07151      00 0 00000              DEC     61331
           00 1 67623
07152      00 0 00000              DEC     58227
           00 1 61563
07153      00 0 00000              DEC     55202
           00 1 53642
07154      00 0 00000              DEC     52258
           00 1 46042
07155      00 0 00000              DEC     49395
           00 1 40363
07156      00 0 00000              DEC     46613
           00 1 33025
07157      00 0 00000              DEC     43911
           00 1 25607
07160      00 0 00000              DEC     41290
           00 1 20512
07161      00 0 00000              DEC     38750
           00 1 13536
07162      00 0 00000              DEC     36290
           00 1 06702
07163      00 0 00000              DEC     33911
           00 1 02167
07164      00 0 00000              DEC     31613
```

```
                00 0 75575
07165           00 0 00000                DEC      29375
                00 0 71323
07166           00 0 00000                DEC      27258
                00 0 65172
07167           00 0 00000                DEC      25202
                00 0 61162
07170           00 0 00000                DEC      23226
                00 0 55272
07171           00 0 00000                DEC      21331
                00 0 51523
07172           00 0 00000                DEC      19516
                00 0 46074
07173           00 0 00000                DEC      17782
                00 0 42566
07174           00 0 00000                DEC      16129
                00 0 37401
07175           00 0 00000                DEC      14556
                00 0 34334
07176           00 0 00000                DEC      13064
                00 0 31410
07177           00 0 00000                DEC      11653
                00 0 26605
07200           00 0 00000                DEC      10323
                00 0 24123
07201           00 0 00000                DEC      9073
                00 0 21561
07202           00 0 00000                DEC      7903
                00 0 17337
07203           00 0 00000                DEC      6815
                00 0 15237
07204           00 0 00000                DEC      5806
                00 0 13256
07205           00 0 00000                DEC      4879
                00 0 11417
07206           00 0 00000                DEC      4032
                00 0 07700
07207           00 0 00000                DEC      3266
                00 0 06302
07210           00 0 00000                DEC      2581
                00 0 05025
07211           00 0 00000                DEC      1976
                00 0 03670
07212           00 0 00000                DEC      1452
                00 0 02654
07213           00 0 00000                DEC      1008
                00 0 01760
07214           00 0 00000                DEC      645
                00 0 01205
07215           00 0 00000                DEC      363
                00 0 00553
07216           00 0 00000                DEC      137
                00 0 00211
07217           00 0 00000                DEC      70
                00 0 00106
07220           04 0 36020     MAX        BCD      /43+
                20 2 02020
07221           00 0 00000     GLOP       OCT      200000
                00 2 00000
07222           00 0 00000     GLUM       OCT      100000
                00 1 00000
07223           00 0 07777     BLAM       OCT      000077777777777
                77 7 77777
07224           77 7 70000     BLOT       OCT      777700000000000
                00 0 00000
07225           00 0 00000     BLUB       OCT      70000
                00 0 70000
07226           00 0 00000     GOFER      OCT      0
                00 0 00000
07227           20 2 02063     CLOCK      BCD      /    CLOCK
                43 4 66342
                               ARGLE      EQU      10000
                               VALLE      EQU      13000
```

```
.ALFA        EQU     16000
             END
```

APPENDIX II

CONTROL DATA CORPORATION INPUT AND OUTPUT CODING AND CONTROL LINES

A. 1604

1. Coding

The external function instruction (74) acts in three different modes to give (a) activation of a channel; (b) sensing of a condition at an external equipment or (c) selecting an external equipment to communicate with the computer.

The channel activate sub-instructions 74.1 through 74.6 are interpreted as follows:

74	1 thru 6	Base Execution Address
6 bit operation code	3 bit index (channel) designator	15 bits which specifies the initial address for data storage in buffering operation

The sense sub-instruction 74.7 is interpreted as follows:

74	7	1 thru 7	1 thru 7	
sense		3 bit channel selection code	3 bits external equipment code	9 bits condition code which specifies operation being sensed

NOTE: If the sensed condition is met, a <u>full</u> exit from the word is performed. If the sensed condition is not met, a half exit from the word is performed.

The select sub-instruction 74.0 is interpreted as follows:

74	0	1 thru 7		
6 bit operation code	3 bit index	3 bits channel selection code	3 bits external equipment code	9 bits condition code which specifies operation being selected

Select

2. <u>Data and Control Lines</u>

Input equipment to computer

Input data (48 lines)		Comprise two complete cables and two lines of a third cable of a buffer or transfer cable group
Input data ready (1 line)	Function:	Indicates equipment input register contains information which computer may sample.
	Operation:	Turned off by input data resume from computer. (Computer re-sync circuitry orients itself about leading edge of ready signal; auxiliary scanner is stopped and input word is passed to computer.)

Computer to Input Equipment

Input data resume (1 line)	Function:	Indicates to equipment that computer has accepted input word.
	Operation:	Turned off by input data ready; turned on when computer has accepted and stored input word.

Computer to Output Equipment

Output (48 lines)		Comprise two complete cables and two lines of a third cable of a buffer or transfer cable group.
Output data ready (1 line)	Function:	Accompanies output data from computer.
	Operation:	Turned on when computer has word of information ready for equipment; off by resume from equipment.

Output Equipment to Computer

Output data resume (1 line)	Function:	Indicates that equipment has accepted word.
	Operation:	Turned on when equipment has accepted word. (Computer resync circuitry orients itself about the trailing edge of resume; when signal drops auxiliary scanner stops and another word is exchanged. Computer prepares a word for exchange while output data resume signal is up.)

Computer to External Equipment

External Function (12 lines)	Function:	Carries external function (EF) codes to select or sense a condition within the equipment
	Operation:	Lines continuously monitored by all equipment. Appropriate function or sense ready alerts equipment on a

		i[illegible]el t[illegible]gle EF code on lines.
External Master	Function:	Clears all equipment on all channels.
Clear (1 line)	Operation:	Occurs when clear switch at console is in ON position.

External Equipment to Computer

Sense response	Function:	Indicates equipment's reply to sense code.
	Operation:	ON indicates presence of condition specified by sense code; OFF indicates absence of condition.
Interrupt (1 line)	Operation:	External equipment or internal computer control sends signal when a condition arises that was previously selected by a 74.x.

Computer to Input Equipment

Input function ready (1 line)	Function:	Accompanies EF select code
	Operation:	Turned on by instruction 74.x. Causes input equipment to translate EF code.
Input sense ready (1 line)	Function:	Accompanies EF sense code
	Operation:	Turned on by instruction 74.7. Causes input equipment to translate EF code and send response back to computer.
Input buffer active (1 line)	Function:	Indicates computer is prepared to receive a block of data.
	Operation:	Turned on when input buffer channel

is activated by instruction 74.1, 74.3 or 74.5. Remains on until final word of block is entered in storage.

Computer to Output Equipment

Output Function Ready (1 line)
- Function: Accompanies EF select code.
- Operation: Turned on by instruction 74.0. Causes output equipment to translate EF code.

Output Sense Ready (1 line)
- Function: Accompanies EF sense code.
- Operation: Turned on by instruction 74.7. Causes output equipment to translate EF code and send response back to computer.

Output Buffer Active (1 line)
- Function: Indicates computer is prepared to transmit a block of data.
- Operation: Turned on when output buffer channel is activated by instructions 74.2, 74.4, or 74.6. Remains on until final word of block is transmitted to output equipment.

B. 160

1. Coding

The computer controls the operation of its external equipment by issuing 12 bit function codes. This process, initiated by the external function (75) instruction, places a designated 12-bit code on the output lines and activates the *function ready* signal. Each external equipment receives the data, but only the equipment recognizing it responds to it by sending back a *function resume signal*.

[illegible] code is built into the [illegible], but one of the [illegible]-bit function [illegible] may be used [illegible] a status request from the external equipment. The equipment must be designed to place a 12-bit status response code on the input cable. The [illegible] must then process this response through an input instruction [illegible] (76) which will bring the 12 bits into the "A" register. The status response must be a one out of twelve response for each condition as more than one condition may exist. This allows for only twelve possible conditions for sensing to be designed into any external equipment.

Normal input and output are handled by the INT (7[illegible]) and [illegible] (73) commands respectively. These operate on blocks of memory.

2. Data and Control Lines

INPUT CABLE LINES	FUNCTION
Input Data and Input Status (12 lines)	Dual Purpose: 1) As data lines they hold equipment input register contents which the computer may sample. 2) As input status lines they indicate equipment's response to status request interrogation.
Input Ready (1 line)	Indicates that the external equipment contains information which the computer may sample. (Computer resync circuits are oriented about the leading edge of the ready signal.)
Input Request	Indicates to external equipment that computer

(1 line)	has completed input data. [illegible] to [illegible] input ready.
Input Disconnect (1 line)	Indicates to computer that input device has no more data to deliver. Computer is then free to resume main program with no further delay. (Generally the input instruction establishes a storage field block of greater capacity than the anticipated input information block.)

OUTPUT CABLE LINES	FUNCTIONS
Output Data and Output Function ([illegible] lines)	Continuously monitored by all equipment. Dual purpose: 1) As output data lines they hold output word which the external device may sample. 2) As output function lines they carry external function (EF) codes to select or sense a condition within the equipment. Function ready alerts the equipment to sample the EF code.
Function Ready (1 line)	Accompanies EF code. It is turned on by instruction [illegible] and causes the equipment to examine the EF code. It is turned off by an output resume from the external equipment.
Information Ready (1 line)	This signal accompanies the output data word from the computer and is turned on when the computer has a word of information ready for the

external equipment. It is turned off by an output resume from the equipment.

Output Resume (1 line)	This signal is turned on when the external device has accepted the output word or EF code. (The computer resync circuitry orients itself about the trailing edge of the resume; when the signal drops the word is exchanged.) The computer prepares a word while the signal is up.
Master Clear (1 line)	This signal clears all external equipment. It occurs when the Load-Clear switch at the console is in the Clear (down) position.

Thesis
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